

Transactions of *American Society* *for Steel Treating*

Vol. XII

November, 1927

No. 5

FEATURES

Deep Etch Test for Iron and Steel— *H. G. Keshian* 689

Carburizing Iron by Mixtures of Hydrogen and Methane—
W. P. Sykes 737

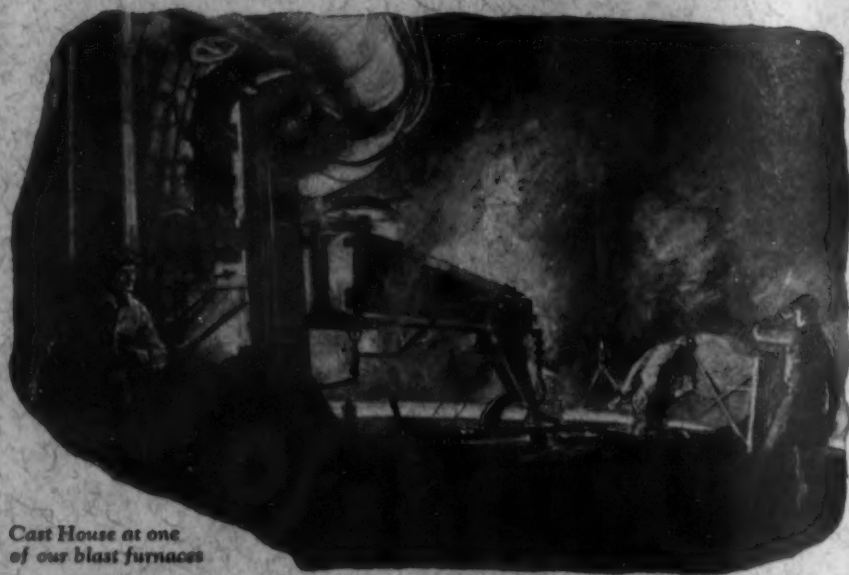
Heat Treatment of Two Ball Bearing Steels— *Bengt Kjerrman* 759

A Critical Study of the Bend Test as Applied to Iron and
Steel— *A. B. Kinzel* 778

Design from the Heat Treating Standpoint— *G. M. Eaton* 794

Facts and Principles Concerning Steel and Heat Treatment—
Part XV— *H. B. Knowlton* 814





Cast House at one
of our blast furnaces

Supervision at the Source

ALLOY Steels of Agathon quality do not "just happen." Every step of their production from ore to finished steels is under strict supervision. The ore and limestone must meet our rigid tests and specifications. The coke is produced in our own ovens. We make our own pig iron in our own blast furnaces—the newest and most modern in America. Strict adherence to formula and painstaking care in every step of production—all are reflected in the high quality and reputation with which Agathon Alloy Steels are regarded by American industries.

Have you a copy of our Agathon Alloy Steel handbook?

We have daily production in our two completely equipped plants at Massillon and Canton in all kinds of Agathon Alloy Steels, such as:

Nickel, Chrome-Nickel
U.M.A., Molybdenum
Chrome-Molybdenum
Nickel-Molybdenum
Vanadium
Chrome-Vanadium
Chromium, etc.

Delivered in Blooms,
Billets, Slabs, Hot Rolled,
Heat Treated, and Cold
Drawn Bars, Hot Rolled
Strips, etc.

Central Alloy Steel Corporation, Massillon, Ohio

World's Largest and Most Highly Specialized Alloy Steel Producers

Makers of Toncan Copper Mo-lyb-den-um Iron

Cleveland
Syracuse
San Francisco

Detroit
Philadelphia
Chicago

Los Angeles
New York
Tulsa

St. Louis
Seattle
Cincinnati



AGATHON ALLOY STEELS

TRANSACTIONS

American Society for Steel Treating

VOL. XII

NOVEMBER, 1927

NO. 5

DEEP ETCH TEST FOR IRON AND STEEL

By H. G. KESHIAN

Abstract

This paper deals with a discussion of the deep etch test for iron and steel and describes the types of structure revealed by the method. It discusses the factors influencing the results, such as the method of melting, chemical composition, reduction of area, heat treatment, the direction of fiber in the steel, etc.

It points out the value and the limitations of the method based on the relation of various etch structures to the performance of the steel in service as observed by the author.

THE deep etch test of steel consists of subjecting the metal to the action of certain acids to reveal its structural features. It was first used by Sorby about forty years ago, which he described in the Journal of Iron and Steel Institute in 1887. Since then it has been used quite extensively in the examination of ingots and rail sections. Its application to the field of tool steels, however, appears to be comparatively recent, where it has received wide-spread attention within the last several years. Due to the simplicity and convenience with which it can be applied, it is steadily gaining ground both in laboratory examination of steel and in inspection in industrial plants. Both the steel mills and the consumers are gradually appreciating the real merits and the limitations of the method; as a result, most of the early opposition shown to deep etch test by the steel makers as a means of inspection

A paper presented before the ninth annual convention of the Society held in Detroit, September 19 to 23, 1927. The author, H. G. Keshian, a member of the Society, is metallurgist with Chase Companies, Inc., Waterbury, Conn.

has disappeared, and at present a considerable amount of tool steel is being handled subject to the etch test.

The test is a most useful means of detecting the structural defects in steel. If properly manipulated, it has a wide field of application. It shows to a certain extent the history of the steel from the ingot to the finished bar; to a certain extent it indicates the amount and the direction of the work which the metal has received. This last feature is particularly useful as an aid to the study of the plastic deformation of iron and steel parts made by drop forging, stamping, or by pressing, and helps in properly designing tools and laying out operations.

ETCHING REAGENTS

Some of the etching reagents employed are as follows:

1. *Ammonium persulphate*:

This solution is made up by dissolving about two grams of ammonium persulphate in ten cubic centimeters, or about $\frac{1}{3}$ of an ounce of water, and is used to bring out general structural conditions of the steel. The specimen is first polished on a medium grade of emery cloth free from deep scratches. It is then rubbed with a piece of cotton dipped in a freshly prepared solution, and is then washed in running water. The test shows better results with straight carbon steel and wrought iron than alloy steels, such as chromium, chromium-vanadium, nickel, chromium-nickel and tungsten steels.

2. *Heyn's Reagent*:

This reagent consists of a solution of 10 grams of copper ammonium chloride in 100 cubic centimeters of water.

The specimen must be polished free from scratches and must be set in a dish, face up, and covered with the solution. On the specimen there will be a deposit of copper, which can be washed off with a piece of cotton. Areas high in carbon, sulphur, and phosphorus will darken.

3. *Humfrey's Reagent*:

This etching reagent consists of ten grams of copper ammonium chloride, 5 cubic centimeters of hydrochloric acid and 100 cubic centimeters of water.

Humfrey's reagent is used to bring out greater detail of structure. The specimen should be finely polished and is then dipped

in Heyn's reagent until all the scratches have disappeared. The reagent then is applied, successively increasing the acidity each time. To secure greater relief the deposited copper should be washed off and the specimen dried and rubbed with fine emery cloth.

HYDROCHLORIC ACID

One part hydrochloric acid in one part of water is generally used, hot. The specimen is put face up in a porcelain dish and covered with the solution. It is then set on a hot plate and kept just below the boiling point from one-half to one hour. The specimen is then taken out with a pair of tongs and rubber gloves, washed in hot water, and then rinsed in alcohol. It will disclose the general features of the steel and is widely used as an excellent deep etching reagent. As the gases given out by the acid are poisonous a means of carrying away the fumes must be provided. The same precaution should be taken when using the other acids that are described in this paper.

NITRIC ACID

Ten to fifteen per cent of the acid either in alcohol or water is used. It is a good mixture to reveal fine cracks and general segregations, but it is not delicate enough for minute segregations. The structure produced is generally "flat" and has less contrast or relief, due perhaps, to its quicker action. It was first used by Sorby in 1887.

SULPHURIC ACID

From ten per cent to twenty per cent of the acid in water is used, hot. It appears to have preferential attack on sulphide inclusions in steel and in general is not as satisfactory as other acids or their combinations.

COMBINED ACIDS

Various combinations of hydrochloric and sulphuric acids are used. Waring and Hoffmann in 1919 used nine parts hydrochloric, three parts sulphuric, and one part of water for etching rail sections. They heated the solution to 212 degrees Fahr. and left the specimen in it for two hours, securing excellent results. It is one of the best deep etching solutions to bring out general structural details of the steel. Sauveur's reagent consists of three parts of

water, two parts sulphuric acid and one part hydrochloric acid. It is used to develop the general structure of the steel and is applied in the same manner as the other combined acids.

The following combinations will give excellent results as an all-round deep etching solution:

Hydrochloric acid	500 cubic centimeters
Sulphuric acid	70 cubic centimeters
Water	180 cubic centimeters

This should be made up by mixing the sulphuric acid with the water, and then adding the hydrochloric acid. It is better to cool the first before adding the hydrochloric acid.

The following procedure is recommended. The specimen need not be finely polished; a reasonably smooth surface free from very deep scratches will be sufficient. The specimen is first put face up in an evaporating dish and is covered with the solution. After the specimen has been covered with solution, the dish is set on a hot plate and the solution is kept just below the boiling point. An effective means to carry away the poisonous fumes should be provided. High carbon and alloy steels will require from one to two hours, and low carbon steels from one-half to one hour to properly etch. The specimen is then washed in hot water and dried in alcohol to neutralize any trace of acid. If a little oil is rubbed over the specimen with the palm of the hand rusting may be much retarded. A thin coat of lacquer will also keep the specimen in good shape for a long time.

CHOICE OF ETCHING SOLUTIONS

As a general remark on the choice of deep etching solutions it might be said that, when the deep etch is to be used mostly to inspect large quantities of steel, an etching solution should be selected that can be applied on a large scale, easily and economically; it must give the greatest amount of information on the structure of the steel and must be applicable to as many types of steel as possible. Some of the reagents described above are suitable to bring out certain types of structure; others require a finely polished specimen and demand constant rubbing and attention. For general use, therefore, hydrochloric acid or its combination with sulphuric acid appears to be the best.

Fig. 1
6.75 Inche

Th
vary g
show s
or por
slimy.
from c
signs.
No
dicate
identif
W

1927

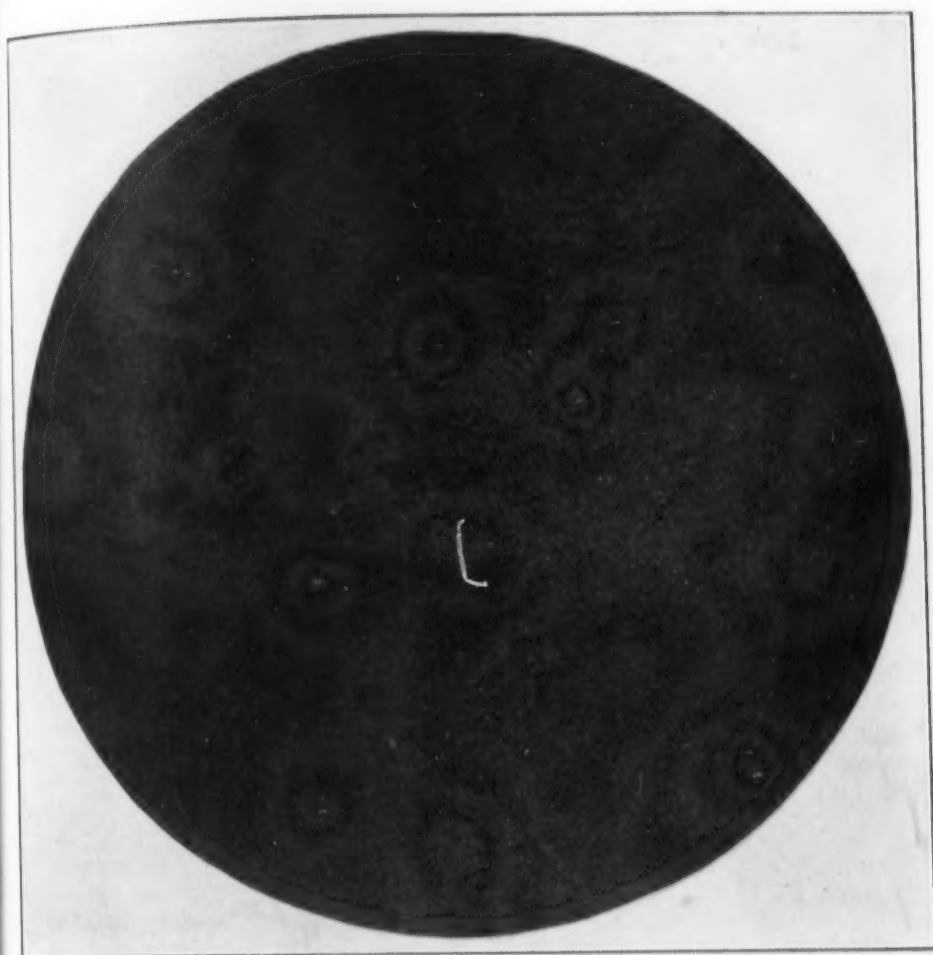


Fig. 1—A Very Unsound Bar of Carbon Tool Steel After Etch Test. Diameter of Bar 6.75 Inches, Carbon 1.06 Per Cent, Manganese 0.31 Per Cent.

TYPES OF ETCH STRUCTURE

The structures revealed by deep etching are numerous, and vary greatly. After the etch the surface of the specimen may show seams, laps, cracks, pipes, or pin-holes. It may appear dense or porous, smooth or rough, dark or light colored, granular or slimy. The structure may be wholly or partly dendritic, or free from dendrites. It may show a so-called pattern, of various designs.

Now the question that arises is, which of these structures indicate good steel, which poor steel? In other words, can one identify good steel from a poor steel by the deep etch test?

When a piece of steel, after the etch test, shows cracks, pipes,

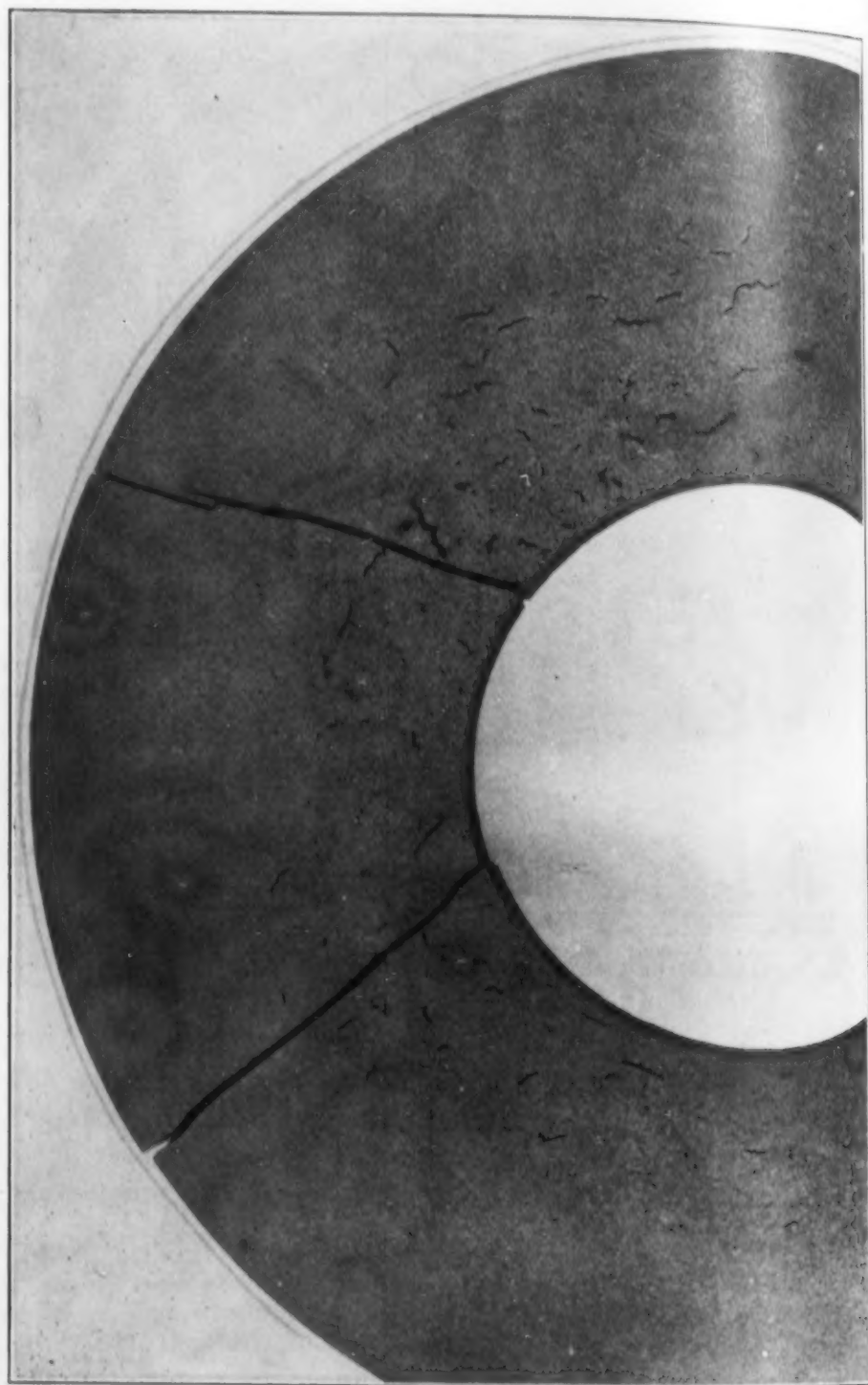


Fig. 2—Section of a Stripping Die Made from Bar Stock Broken in Hardening. Etch Test Shows Numerous Tangential Cracks Which Were Also Found in the Bar. Diameter of Bar 8 Inches. Carbon 1.03 Per Cent, Manganese 0.34 Per Cent.

seams, ho
or any o
can hard
the steel.
one to an
and depe
of exper
with van
many of
tinuity o
the rate



Fig. 3
Note "Snow"

composi
and the
to the c
of thes
fully e
tures to

So
are giv
whose
more t
all of
all sha
in rou
gons a
crucib
etch sa
solution
it was

seams, holes, serious non-metallic inclusions, serious segregations, or any other defect showing a discontinuity of the metal, there can hardly be any doubt as to the unsoundness or inferiority of the steel. Beyond this, however, the question becomes a difficult one to answer and the deep etch test loses greatly in simplicity and dependability. The intelligent use of it then becomes a matter of experience and good judgment, gained by practical experience with various types of etch structures in actual service. A good many of the etch structures other than those that show discontinuity of the metal depend largely on the method of manufacture, the rate of cooling of the metal in the mold, and its chemical



Fig. 3—Section of a Cut and Draw Die 5 Inches in Diameter Which Failed in Hardening. Note "Snow Flakes". Carbon 0.90-1.00 Per Cent.

composition, the amount of reduction from ingot to finished bar, and the kind of heat treatment which the steel has received previous to the etch test. Therefore, it is necessary that the inter-relations of these varying factors and their effects on the etch results be fully considered, as well as the relation of different etch structures to the actual performance of the steel in service.

Some of the factors that affect the results of the deep etch test are given below. They are based on the writer's own experience, whose opportunity it was to examine and watch in service more than 1000 tons of low and high carbon tool and alloy steels, all of which were subjected to the deep etch test. These included all shapes, and ranged in size from one to ten inches in diameter in rounds, and from one to six inches in squares, also flats, hexagons and octagons in various dimensions. They were made by crucible, electric, and open-hearth methods, representing over 5000 etch samples produced by several different steel mills. The etching solution used consisted first of Waring and Hoffmann reagent; then it was changed into 500 cubic centimeters hydrochloric, 70 cubic

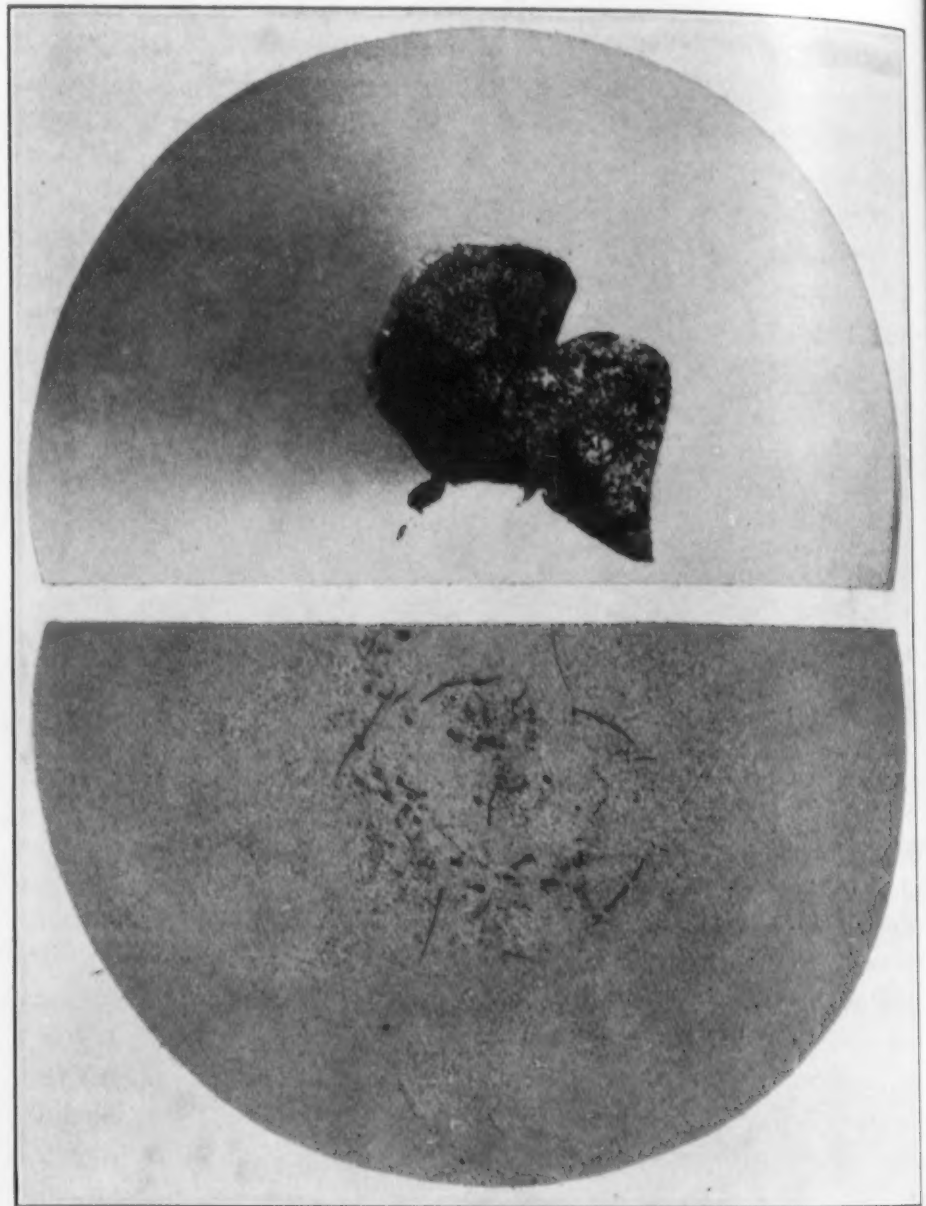


Fig. 4—Photograph of Cracks in an Alloy Tool Steel 4.5 Inches in Diameter, Large Cavities as Shown Above Were Also Found All Along the Length of the Same Bar. Carbon 1.18 Per Cent, Manganese 0.26 Per Cent, Tungsten 1.18 Per Cent, Chromium 0.50 Per Cent, Vanadium 0.15 Per Cent.

centimeters of sulphuric, and 180 cubic centimeters of water, as the latter gave somewhat better results. (With the first solution the greater proportion of the sulphuric acid combined with higher concentration seems to cause an immobile sediment which

Fig. 5—
Carbon 0.85

settles on
solution
kept in
further
during
is not c
thought
some de
surround

EFFECT

Ma

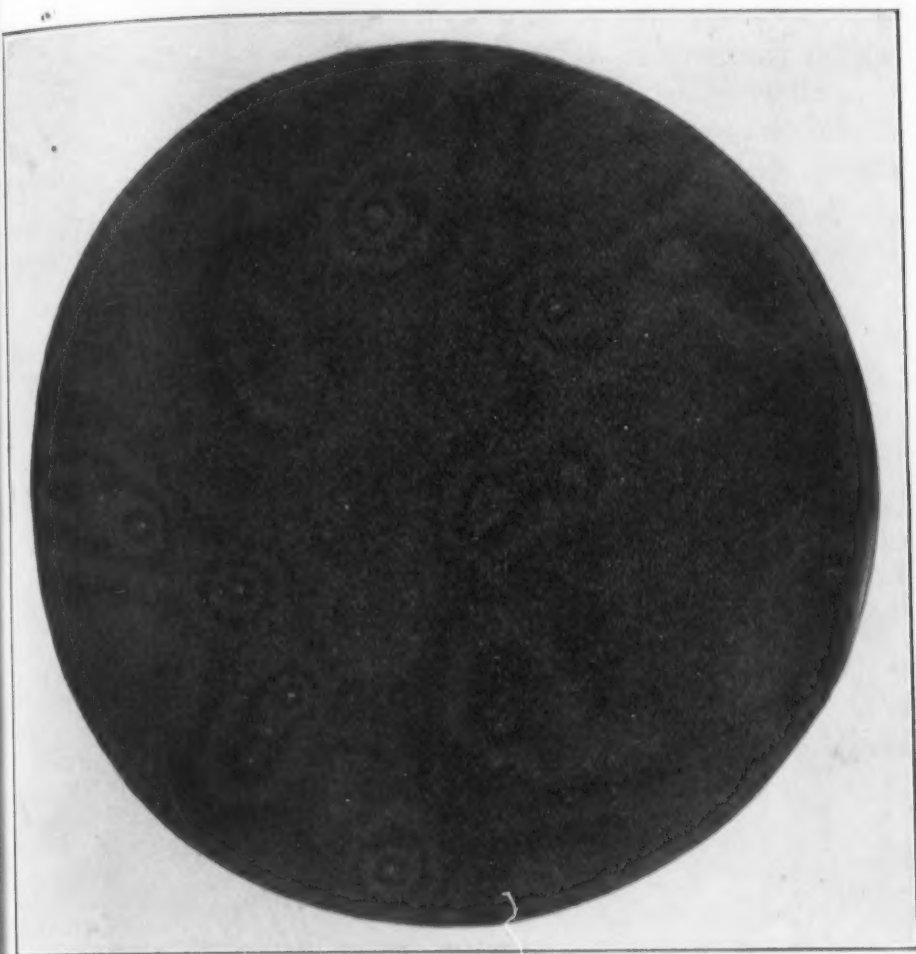


Fig. 5—Finely Divided Inclusions in Carbon Tool Steel. Diameter of the Bar 5.5 Inches, Carbon 0.89 Per Cent, Manganese 0.27 Per Cent.

settles on the specimen and interferes with the free action of the solution to a certain extent.) In all cases the specimens were kept in the solution two hours, just below the boiling point. It is further to be stated that the results which the writer has obtained during his observations are not offered here as conclusive, and it is not expected that the reader will agree in all details with the thoughts expressed therein, but it is hoped that they will help in some degree to eliminate some of the abuse and the opposition that surround this very useful method of test.

EFFECT OF CHEMICAL COMPOSITION ON THE ETCH TEST—TABLE IV

Machinery steel and up to about 0.50 per cent carbon steels

Large Cavities
Carbon 1.18
50 Per Cent,

water, as
at solution
ined with
ent which

show greater solubility than higher carbon steels. Therefore, they appear rougher and darker in color and less dense.

Alloy steels containing 1.5 per cent tungsten usually etch darker and much denser and more uniform than plain carbon tool steels. Chromium-nickel and oil hardening manganese steels generally fall between alloy and high carbon tool steels in appearance. High speed steels, almost uniformly etch very dark and repre-

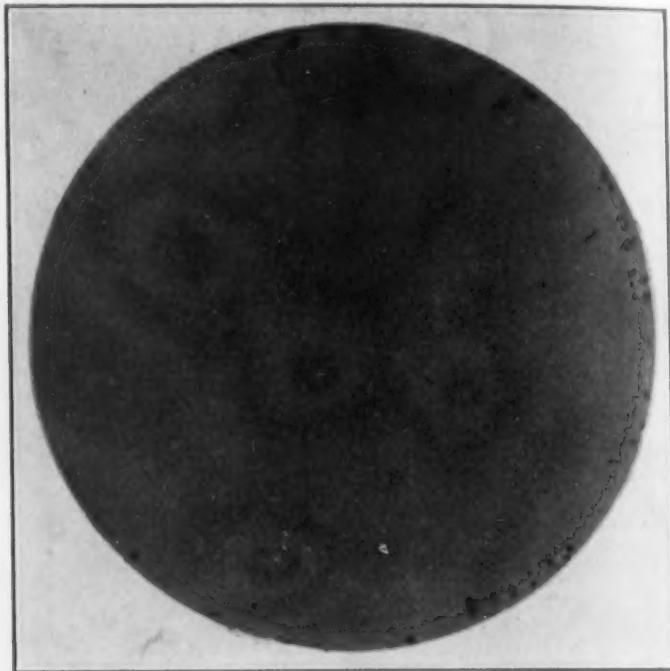


Fig. 6—Subcutaneous Holes in Alloy Tool Steel Intended for Taps. Photograph Shows Disk After Etching. Carbon 1.08 Per Cent, Tungsten 1.55 Per Cent, Manganese 0.28 Per Cent. Diameter of Bar 2.625 Inches.

sent the densest and smoothest appearing structure, followed by hot work type chromium-carbon steels. Straight carbon-vanadium tool steels are somewhat denser than plain carbon steels but do not vary much in color. It is always easy to identify wrought iron from the steels by its lamellar or stringy appearance, but the American ingot iron can scarcely be identified from medium carbon steel, that is, about 50-point carbon steel. It is to be remembered that it is not always easy to draw sharp lines between these groups except perhaps in the case of high speed steels.

EFFECT OF METHOD OF MANUFACTURE ON ETCH TEST

Steels made by crucible and electric furnace process, etch

denser
od, the
But it
steel by

1927

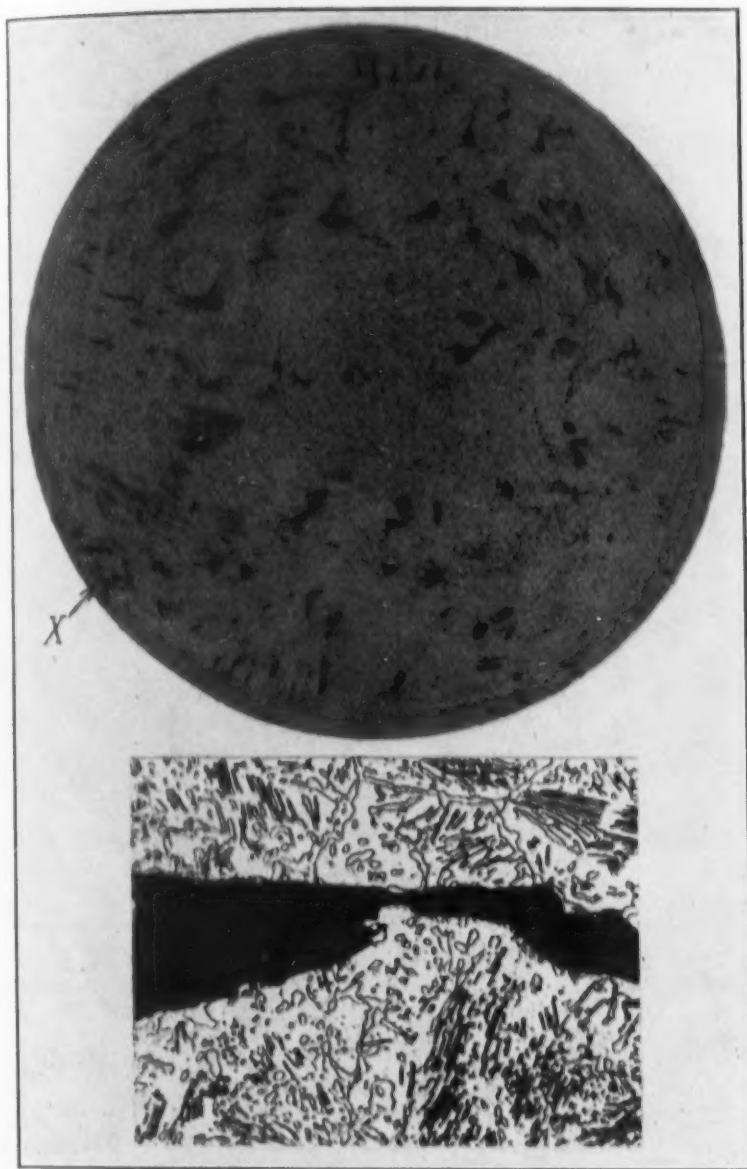


Fig. 7—(Upper) Disk from High Carbon Tool Steel Bar After Etching, Showing Pits and Holes. Diameter of Bar 3 Inches, Carbon 0.98 Per Cent Manganese 0.19 Per Cent. (Lower) Photomicrograph of Section X Etched in 1 Per Cent Nital, 500x.

denser and smoother than those made with acid open-hearth method, the latter etching somewhat darker and appearing granular. But it is not easy to identify crucible steel from electric furnace steel by comparing their etch structures.

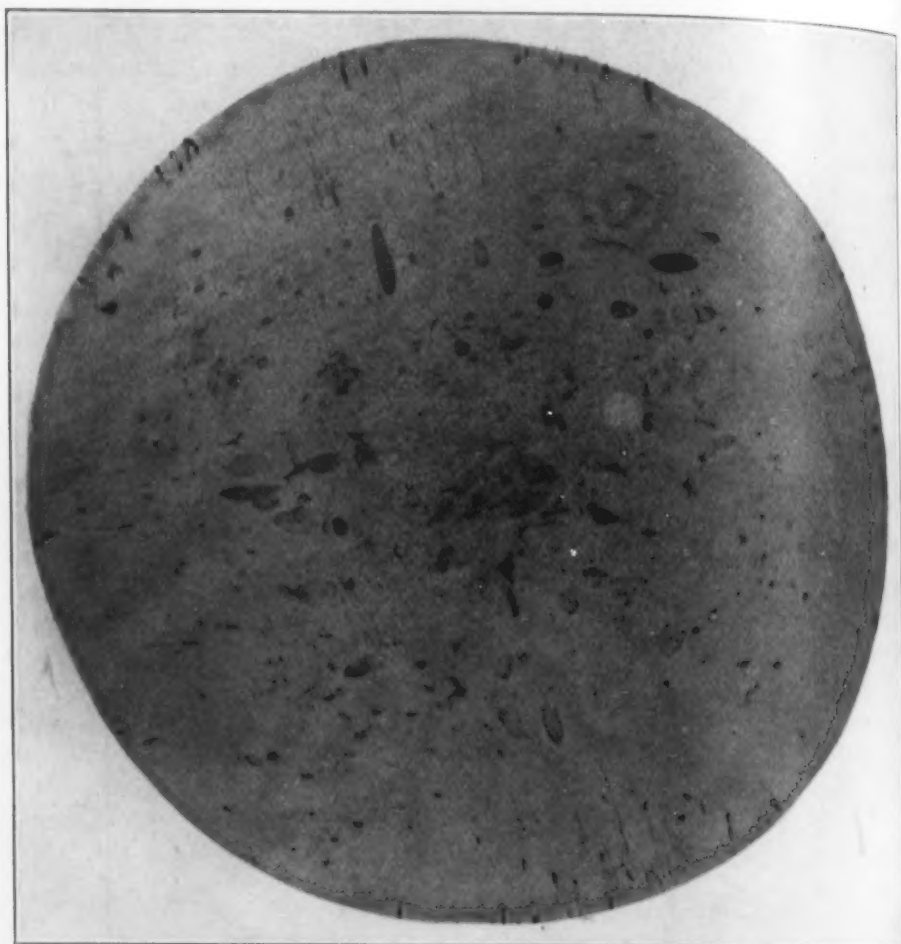


Fig. 8—Example of "Effervescing or Wild" Steel. Disk Taken from the End of the Bar. Diameter of Bar 7 Inches, Length of Bar 10 Feet, Carbon 1.06 Per Cent, Manganese 0.24 Per Cent.

EFFECT OF THE AMOUNT OF WORK DONE ON STEEL

It is often easy to observe the effect of work done on a section of steel by means of the etch test by the difference in appearance. The difference in smoothness of the section indicates the effect of work. This difference in appearance is very evident in the case of a hammered bar originally very dendritic; but in steels where this difference in the sectional area is not well defined, a sample may show coarse structure all over its entire area, yet it cannot be concluded that the piece has not been worked well. If the specimen comes from a well worked bar with a tendency to fibrous structure and then etched on a section perpendicular to the direction of the fibers, the etched structure will appear coarse. This

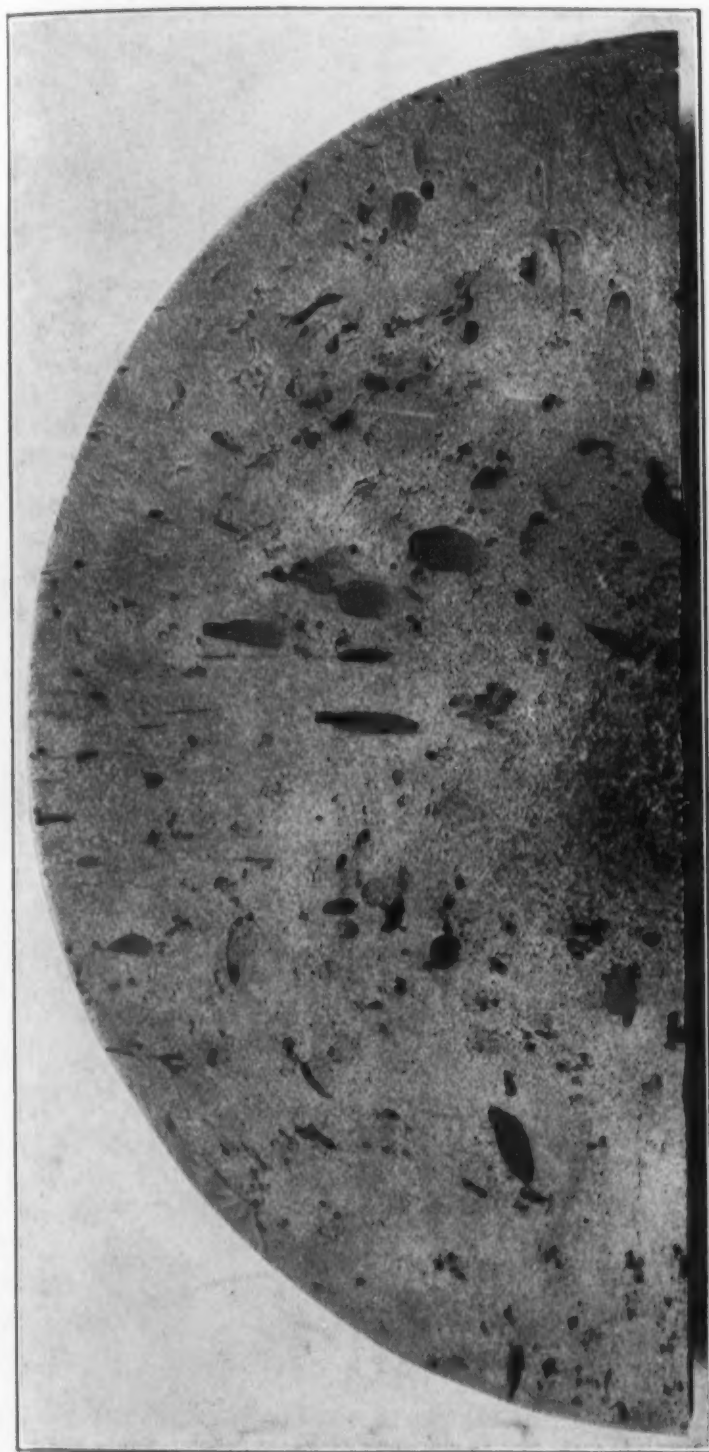


Fig. 9—An Extremely Unsound Bar of Tool Steel Showing Deep Pits After Etching. Diameter of Bar 6 Inches, Carbon 0.83 Per Cent, Manganese 0.30 Per Cent.

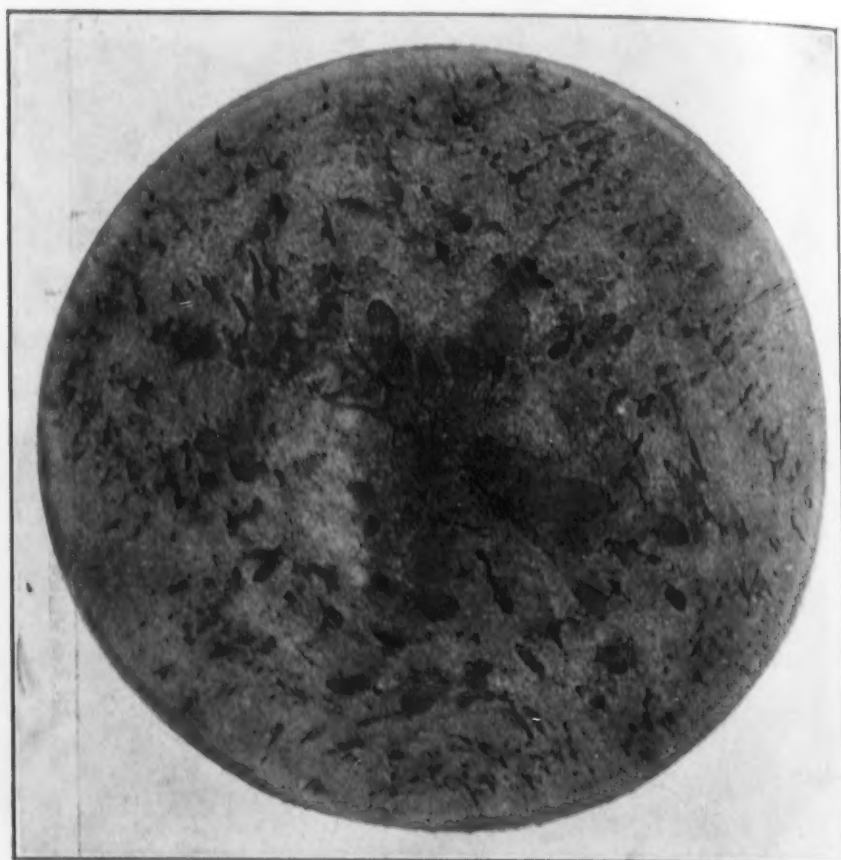


Fig. 10—Sulphide Inclusions in Alloy Tool Steel. Diameter of Bar 3 Inches, Carbon 1.04 Per Cent, Tungsten 1.37 Per Cent, Manganese 0.42 Per Cent, Sulphur 0.03 Per Cent.

is often the case when a very dendritic steel is hammered with big reduction. Therefore the direction of the fiber must also be considered when the etch structure is taken as an indication of the amount of work the steel has received. Fig. 27.

EFFECT OF THE DIRECTION OF THE FIBER ON ETCH STRUCTURE

Steel when etched across the fiber will dissolve faster than when etched with the fiber, a fact well known when all crystalline substances are subjected to erosion. As a result, therefore, transverse sections when etched will appear less dense and look darker than the longitudinal section. This is shown in Table I.

THE EFFECT OF THE TEMPERATURE OF THE ETCHING SOLUTION ON THE ETCH TEST

The temperature of the etching solution has an important

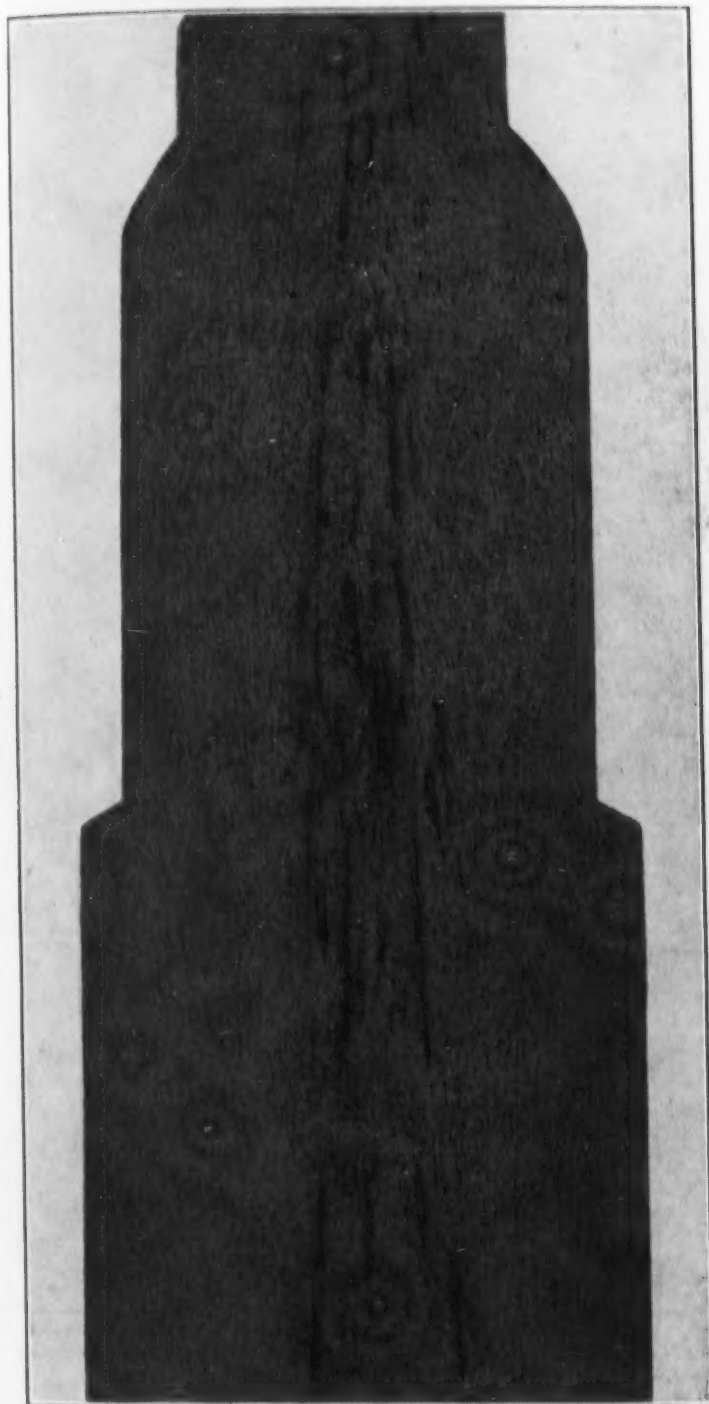


Fig. 11—Stamp Force Split Open in Hardening. Etch Test Shows Elongated Blow-Holes. Carbon 0.90-1.00 Per Cent.

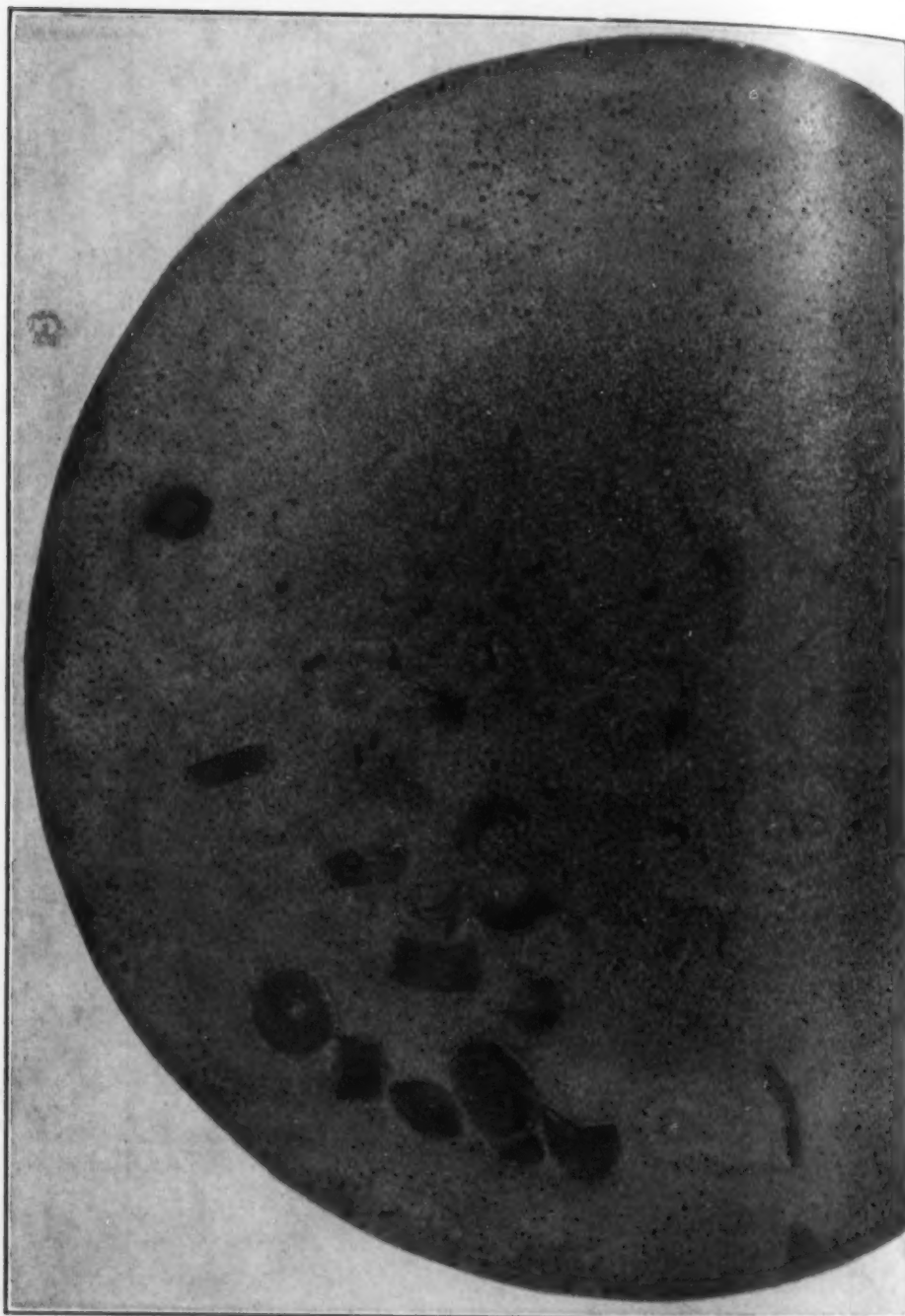


Fig. 12—Scrap and Non-Metallic Inclusions in Carbon Tool Steel. Diameter of Bar 5.5 Inches, Carbon 1.08 Per Cent, Manganese 0.34 Per Cent.

effect on the appearance of the etched surface. The higher the temperature the greater is the solubility of the steel, therefore, the

Effect

Specimens
ac

Material

K—1.5%
N—Stainl
D—High
F—3.5%
A—.20%

B—High
J—High

S—Fast
C—40 po

Mark

A Ma
B Hig
C 40

D Hig
F 3.5
J Hig

K 1.5
N Sta
S Fa

Effect

Specimen

Mat

A—
B—
C—
D—
F—
J—
K—
N—
S—

Table I
Effect of Direction of Rolling on the Solubility of Different Steels in
Hot Acid Etch Test

Specimens were left for two hours in a mixture of 500 parts of hydrochloric, 70 parts sulphuric acid and 200 parts of water, kept at a temperature of 200 degrees Fahrenheit.

Material	Brinell Hardness	Before Etch		After Etch		Relative Loss With Direction of Rolling
		Dia.	Length	Dia.	Length	
K—1.5% Tungsten steel	217	1.130	1.012	1.081	0.958	10.20% more
N—Stainless steel	217	0.751	0.999	0.600	0.772	47.02% more
D—High speed steel	235	0.875	1.023	0.825	0.947	50.20% more
F—3.5% nickel steel	156	0.875	1.016	0.829	0.943	58.70% more
A—.20% carbon machinery steel	118	0.874	1.005	0.786	0.855	70.45% more
B—High carbon tool steel	174	0.875	1.007	0.828	0.922	80.85% more
J—High carbon, chromium tool steel	228	0.875	1.026	0.772	0.810	109.70% more
S—Fast finishing steel	217	0.749	1.000	0.699	0.887	126.00% more
C—40 point carbon, 1.30 manganese steel	192	0.871	1.025	0.762	0.742	159.63% more

ANALYSES OF SPECIMENS

Mark	Material	C	Mn	Si	Cr	Ni	W	Va
A	Machinery steel	0.190	0.76	0.14	.....	.....	.....	.....
B	High carbon tool steel	1.120	0.36	0.19	.....	.....	.....	.....
C	40 point carbon, manganese steel	0.379	1.36	0.18	.....	.....	.....	.....
D	High speed steel	0.652	.....	.....	.....	.....	17.95	0.79
F	3.5% nickel steel	0.161	.....	.....	.....	3.54	.....	.....
J	High carbon chromium steel	2.05	.....	.....	11.42	.....	.....	.....
K	1.5% tungsten steel	1.215	.....	.....	0.56	.....	1.51	.....
N	Stainless steel	0.340	.....	.....	13.58	.....	.....	.....
S	Fast finishing steel	1.303	.....	.....	0.24	.....	3.74	.....

Table II
Effect of Temperature on the Rate of Solubility of Different Steels in
Hot Acid Test

Specimens etched in a mixture of 500 parts of hydrochloric, 70 parts of sulphuric acid and 200 parts of water for two hours at the temperatures indicated.

Material	Loss in Weight in Grams per Square Centimeter		
	At 100° F.	At 150° F.	At 200° F.
A—Machinery steel	0.164	0.582	1.369
B—1.0% carbon tool steel	0.150	0.396	0.803
C—.40% carbon machinery steel	0.333	1.093	1.757
D—High speed steel	0.107	0.411	0.771
F—3.5% nickel steel	0.097	0.300	0.631
J—High carbon, chromium steel	0.368	0.705	1.408
K—1.5% tungsten steel	0.111	0.300	0.594
N—Stainless steel	0.300	0.980	1.871
S—Fast finishing steel	0.145	0.424	0.821

Table III

Effect of Length of Time of Etch on the Solubility of Different Steels

Specimens kept in a mixture of 500 parts of hydrochloric, 70 parts sulphuric and 200 parts of water at a temperature of 200 degrees Fahrenheit for periods of one hour, two hours and four hours.

Material	Loss in Weight in Grams per Square Centimeter		
	1 Hour	2 Hours	4 Hours
A—Machinery steel	0.689	1.369	2.340
B—1.0% carbon tool steel	0.418	0.803	1.666
C—.40% carbon machinery steel	1.374	1.757	2.832
D—High speed steel	0.455	0.771	1.578
F—3.5% nickel steel	0.350	0.631	1.206
J—High carbon, chromium steel	1.008	1.408	2.514
K—1.5% tungsten steel	0.418	0.594	1.124
N—Stainless steel	0.941	1.871	2.460
S—Fast finishing steel	0.370	0.821	1.700

Table IV

Rate of Solubility of Different Steels in Hot Acid Test.

The figures given below are relative and are the averages of results obtained after etching the specimens for two hours at temperatures given in Table II, in a mixture of 500 parts of hydrochloric, 70 parts sulphuric acid and 200 parts of water.

Material	Brinell Hardness	Average Loss in Weight, Grams per Square Centimeter	
		1 Hour	2 Hours
F—3.5% nickel steel	156	0.309	
K—1.5% tungsten steel	217	0.335	
D—High speed steel	235	0.429	
B—1.5% carbon tool steel	174	0.444	
S—Fast finishing steel	217	0.463	
A—Machinery steel	118	0.705	
J—High carbon, chromium steel	228	0.827	
N—Stainless steel	217	1.050	
C—.40% carbon, 1.30% manganese steel	192	1.061	

Table V

Effect of Heat Treatment on the Rate of Solubility of Carbon Steel in Hot Acid Etch Test

Specimens etched for two hours in a mixture of 500 parts of hydrochloric, 70 parts sulphuric acid and 200 parts of water, kept at a temperature of 150 degrees Fahrenheit. The dimensions of specimens, $\frac{3}{4}$ inch in diameter by 1 inch long. Analysis of specimens, carbon, 1.015; manganese, 0.38; silicon, 0.13; chromium, 0.05.

Specimen	Heat Treatment	Loss in Weight in Grams per Square Centimeter		
		Brinell	Rockwell	
T 1	As received	217	20	0.972
T 2	1450 deg. in water	600	64	0.536
T 3	Draw 300 deg. F. for 20 minutes	600	64	0.573
T 4	Draw 400 deg. F. for 20 minutes	578	58.5	0.770
T 5	Draw 500 deg. F. for 20 minutes	555	55	0.780
T 6	Draw 600 deg. F. for 20 minutes	477	52	0.817
T 7	Draw 700 deg. F. for 20 minutes	444	48.5	0.878
T 8	Draw 800 deg. F. for 20 minutes	402	44	0.857
T 9	Draw 900 deg. F. for 20 minutes	340	40	0.857
T10	Draw 1000 deg. F. for 20 minutes	311	36	0.890
T11	Draw 1100 deg. F. for 20 minutes	255	28	0.890
T12	Draw 1200 deg. F. for 20 minutes	223	22	0.866

Steels

200 parts of
1 four hours

meter
4 Hours

2.340
1.666
2.832
1.578
1.206
2.514
1.124
2.460
1.700

etching the
500 parts of

meter

Steel in

parts sulphuric
the dimensions
carbon, 1.015;

in Grams,
centimeter

72
36
73
70
80
17
78
57
57
90
90
66

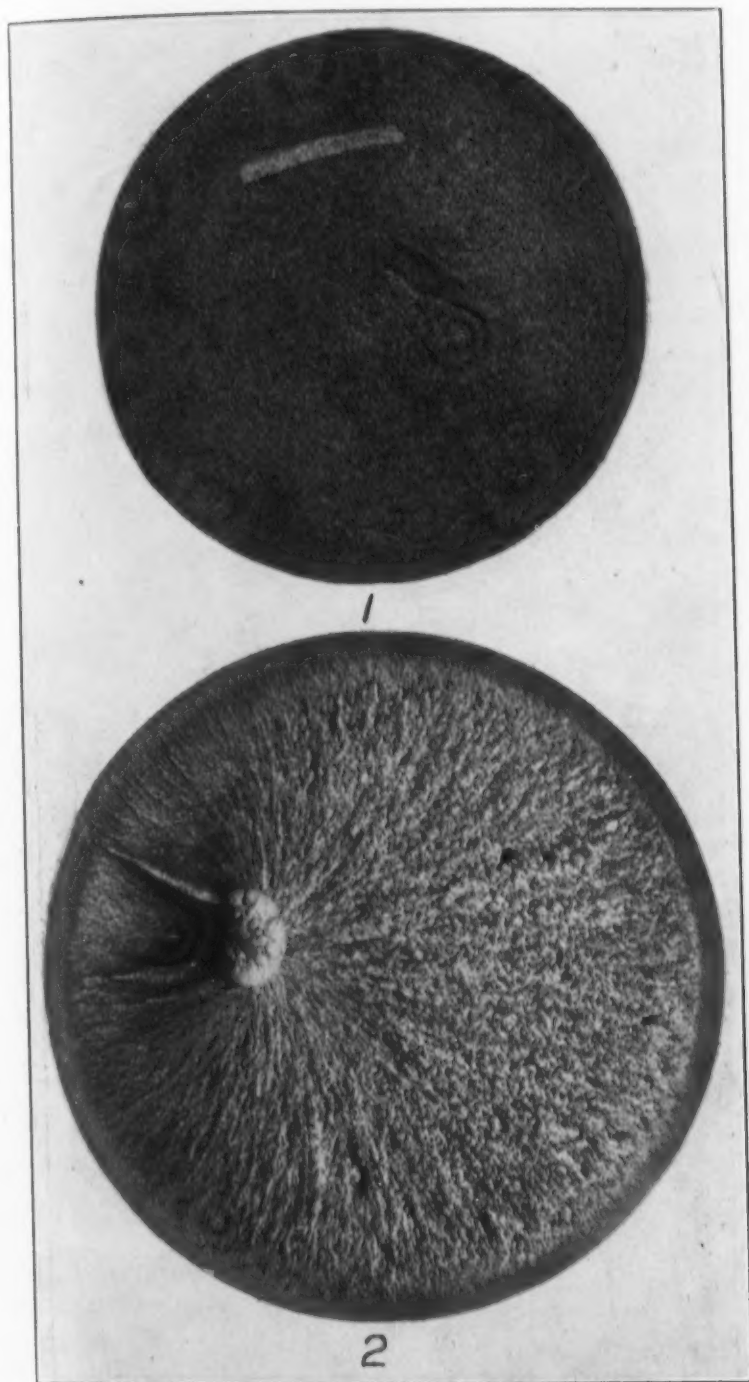


Fig. 13—Scrap Inclusions in 1 Per Cent Carbon Tool Steel. (1) Bar Stock, (2) Part of a Stamp Force, Broken After a Very Short Time in Service.

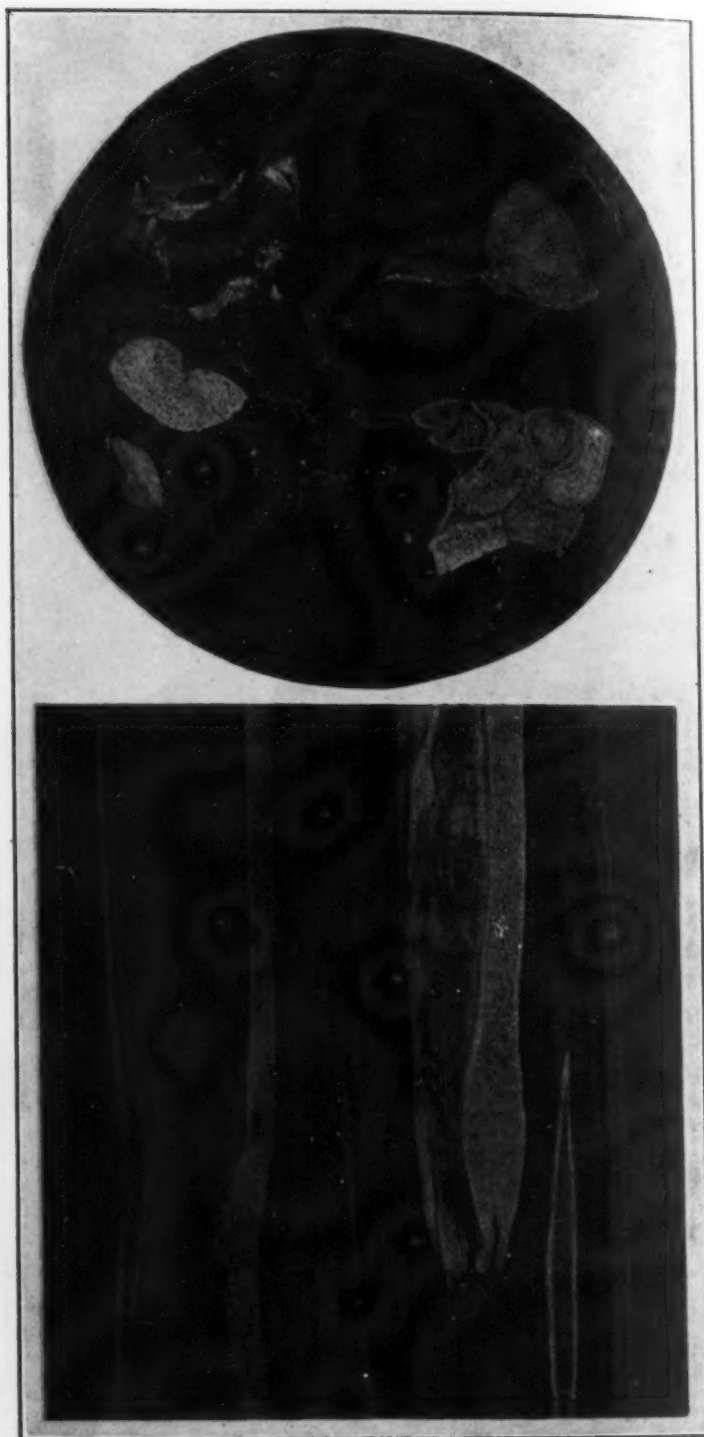


Fig. 14—Structure of a 3-Inch Bar Intended for Machinery Steel. Photomicrograph Shows Transverse and Longitudinal Sections. Both Pieces were Etched in 9:3:1 Mixture for 15 Minutes.

1927

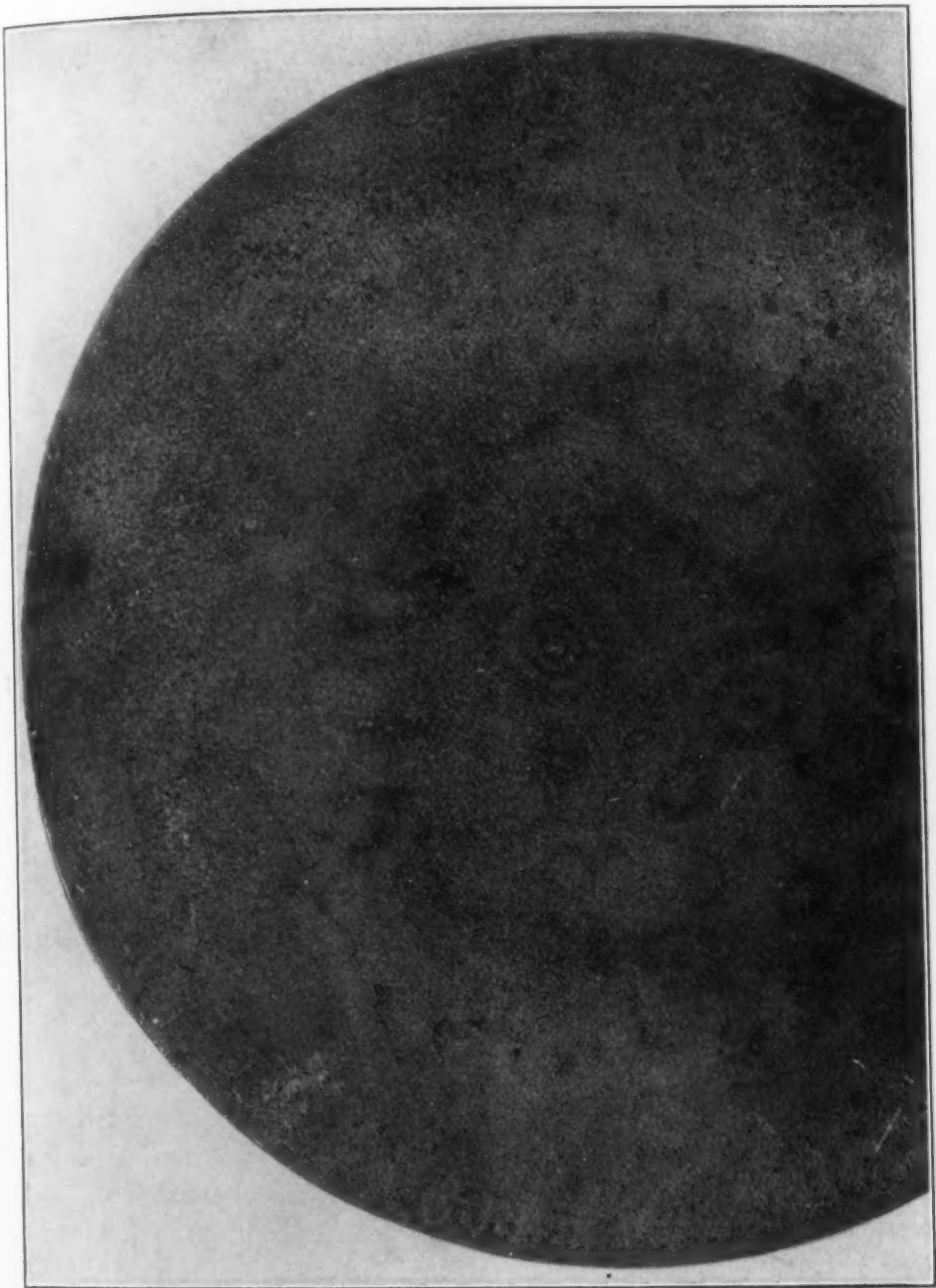


Fig. 15—Segregation in Open-Hearth Screw Stock, Diameter of Bar 5 Inches, Carbon 0.10 Per Cent, Manganese 0.72 Per Cent, Phosphorus 0.083 Per Cent, Sulphur 0.106 Per Cent.

	Carbon	Manganese	Phosphorus	Sulphur
A	0.164	0.82	0.124	0.164
B	0.129	0.83	0.103	0.118

greater is the coarsening effect. The effect of temperature is shown in Table II.

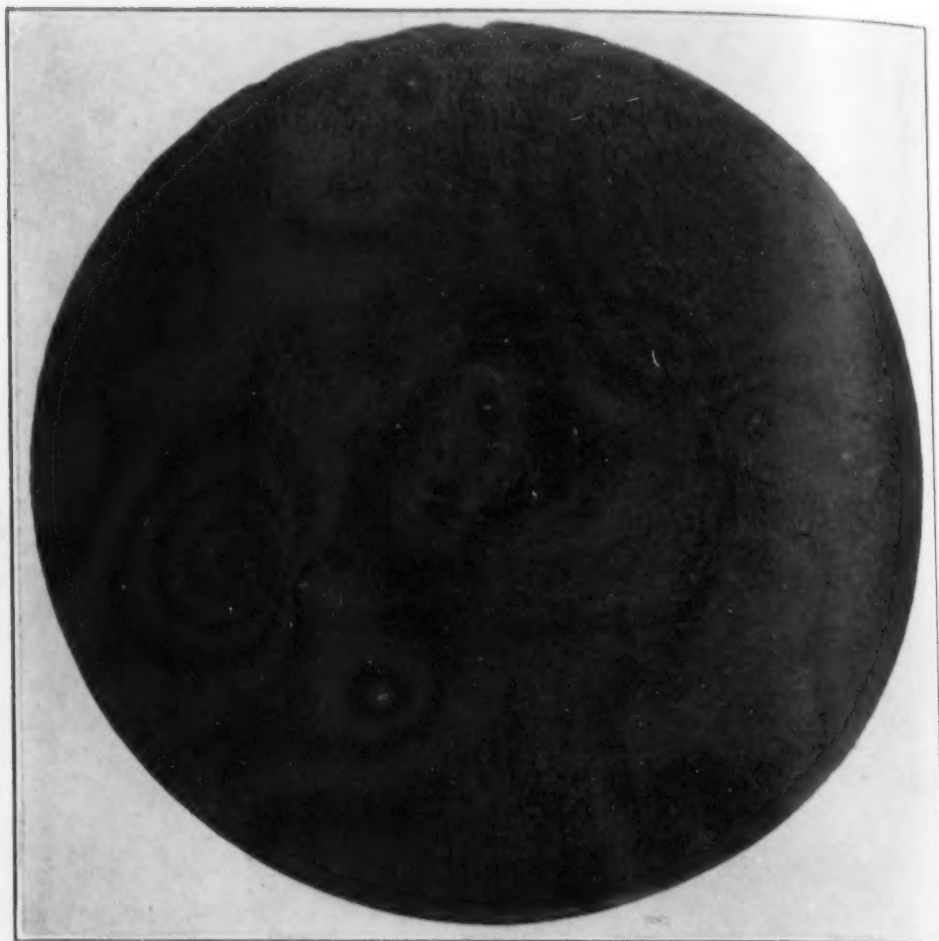


Fig. 19—Segregation in Machinery Steel After Etch Test. Diameter of Bar 6 Inches. Carbon 0.17 Per Cent, Manganese 0.59 Per Cent.

EFFECT OF LENGTH OF TIME OF ETCHING

It is possible to coarsen the structure and produce small pin-holes by prolonged etching. Therefore the etching period should be made as uniform as possible. It must be remembered, however, that a sound and homogeneous steel, even though it may be over-etched, will coarsen uniformly. This is shown in Table III.

EFFECT OF PREVIOUS HEAT TREATMENT ON THE RESULT OF ETCH TEST—TABLE V

Hardened steel will etch dense and smooth. The etch structure of a hardened and tempered piece greatly differs from that of a hardened piece but not tempered. The effect of tempering be-

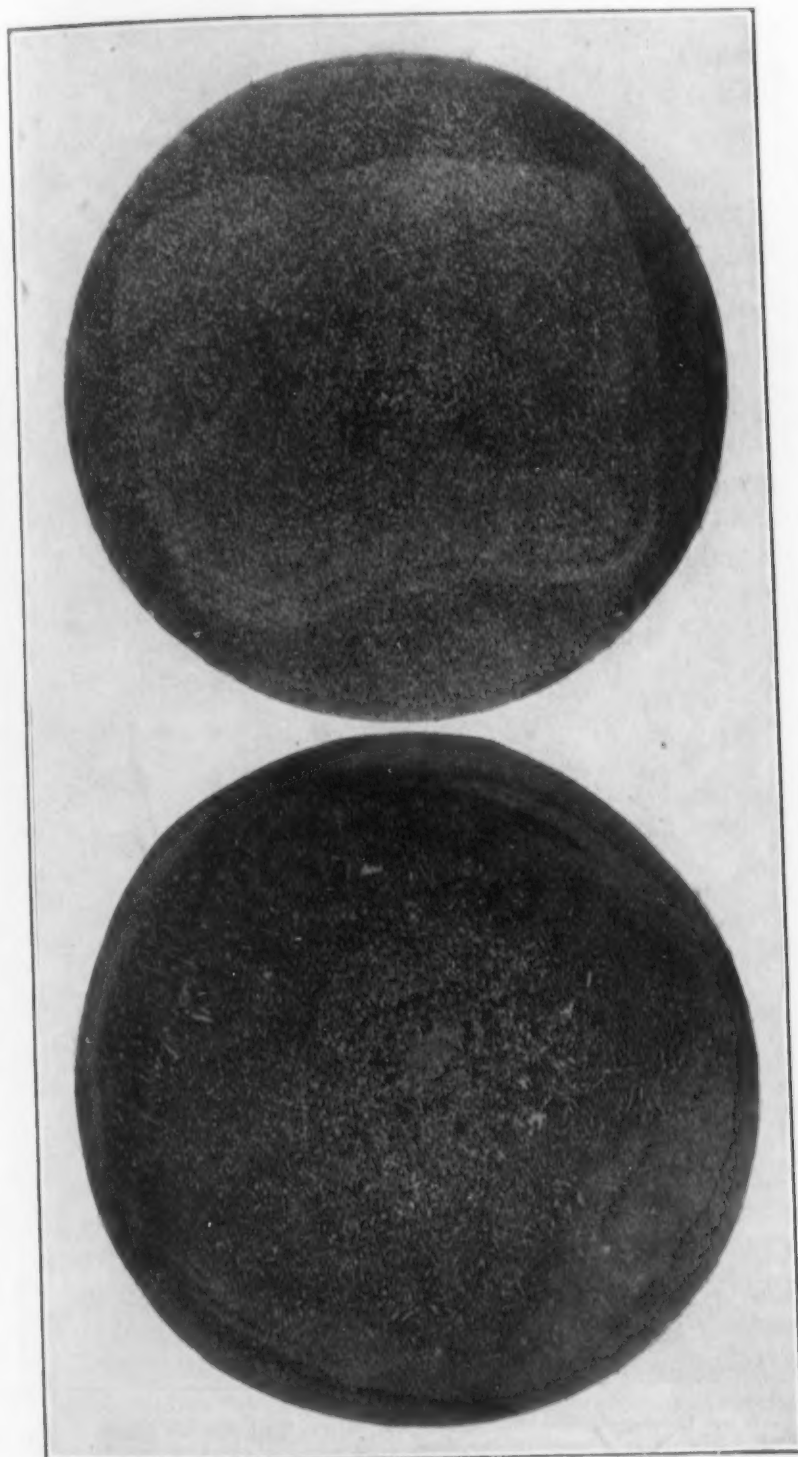


Fig. 17—Segregation in 0.90 to 1.00 Per Cent Carbon Tool Steel.

Inches.

l pin-
should
how-
ay be
III.

OF

struc-
nat of
g be-

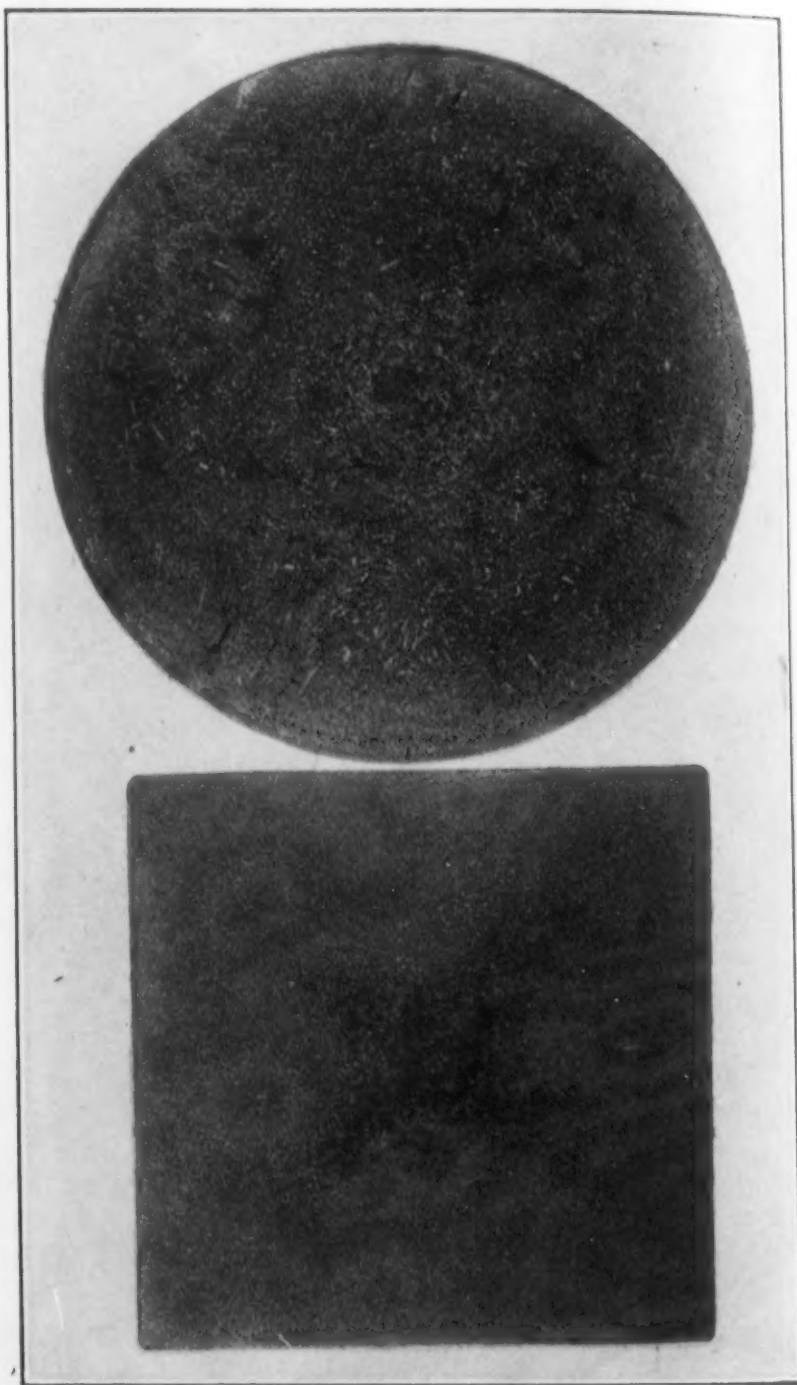


Fig. 18—Segregation in Carbon and Alloy Tool Steel. Upper 1 Per Cent Carbon Steel, Lower 4 Per Cent Tungsten, 1.5 Per Cent Carbon Alloy Steel.

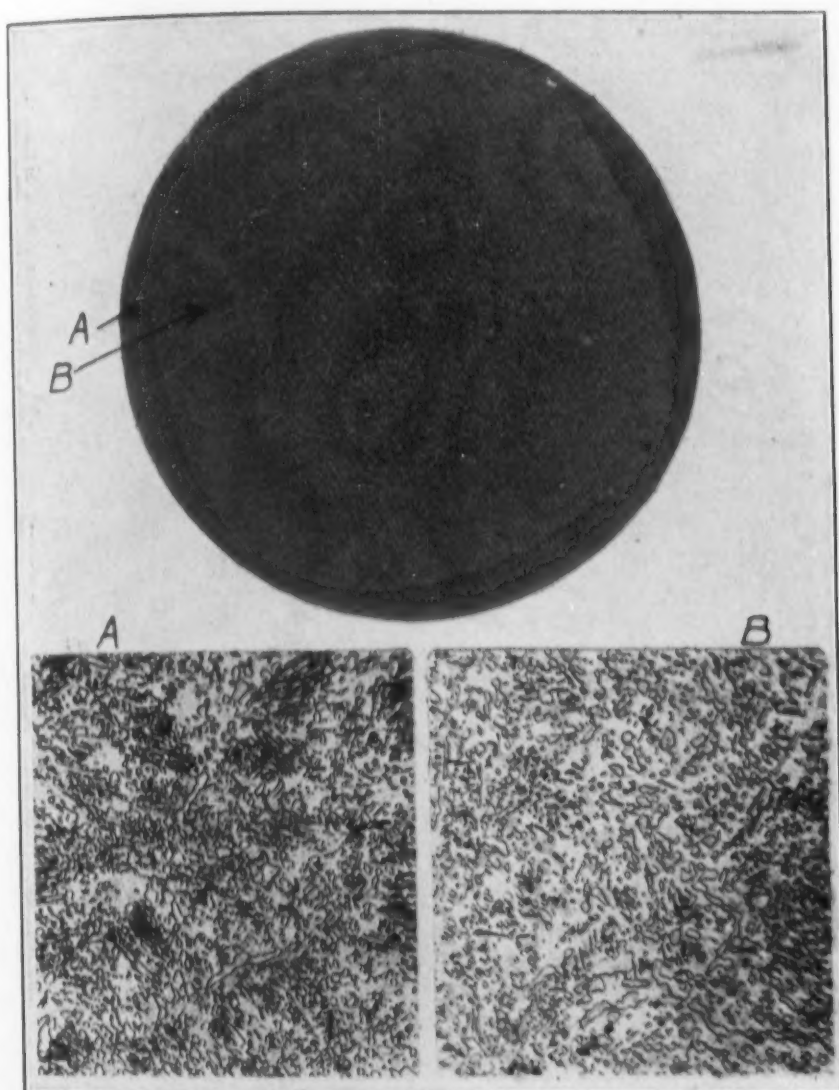


Fig. 19—Upper, Segregation in High Carbon Tool Steel. Diameter of Bar 2.5 Inches, Carbon 1.17 Per Cent, Manganese 0.37 Per Cent. (a) Photomicrograph of Section A, Carbon 1.122 Per Cent, Manganese 0.366 Per Cent, 500x. (b) Photomicrograph of Section at B, Carbon 1.193 Per Cent, Manganese 0.371 Per Cent, 500x.

comes very apparent from 300 up to about 700 degrees Fahr. The effect of intermediate temperatures between 700 and 1200 degrees Fahr. is not so apparent until the steel is thoroughly annealed. Then the structure becomes coarser and shows a complete contrast to that of hardened steel. Hardened steel and tools, however, are liable to crack in hot acid etch. This might happen, even after tempering

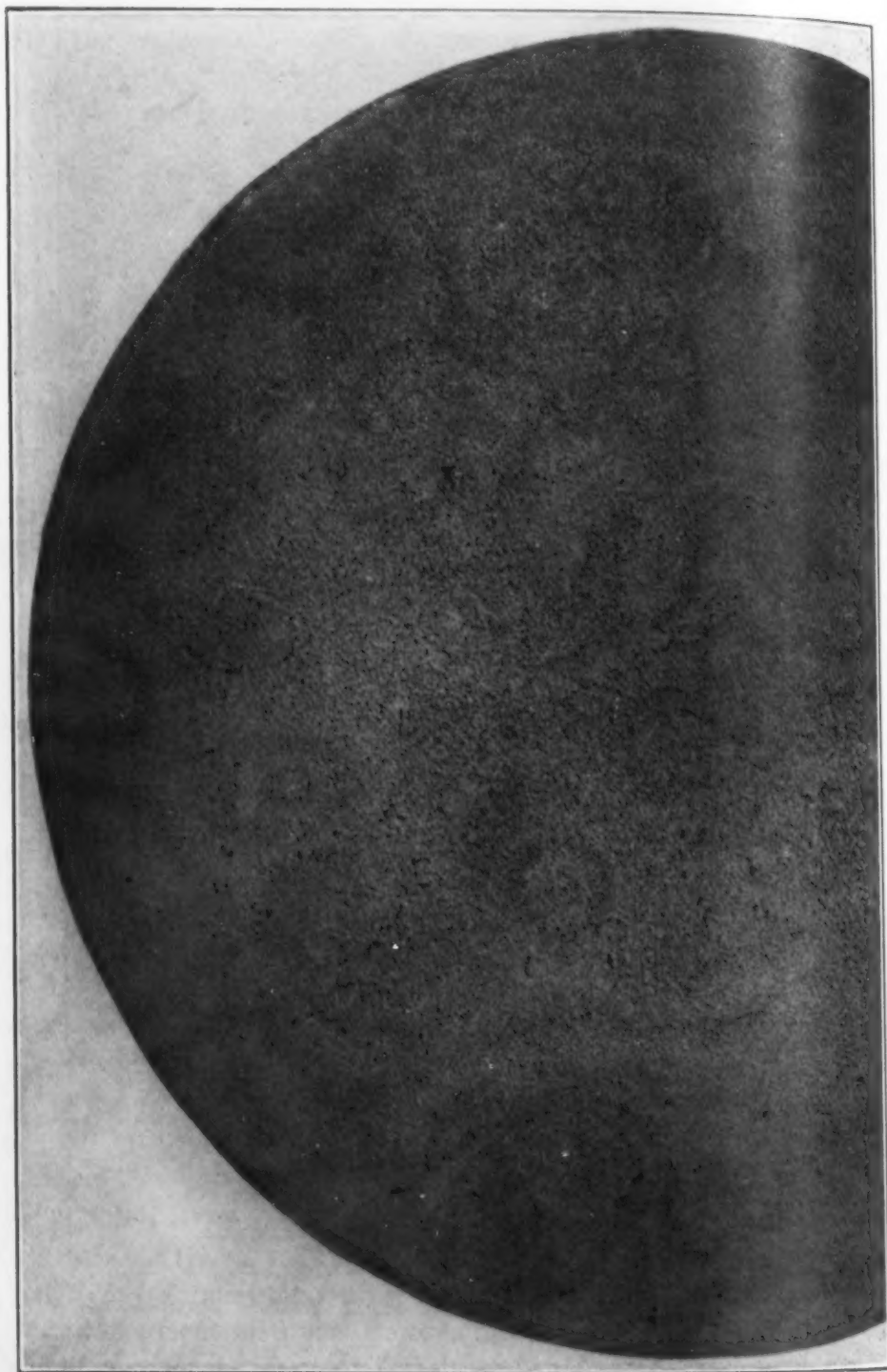


Fig. 20—Structure of a Satisfactory Carbon Tool Steel. Diameter of Bar 6 Inches, Carbon 0.90–1.00 Per Cent.

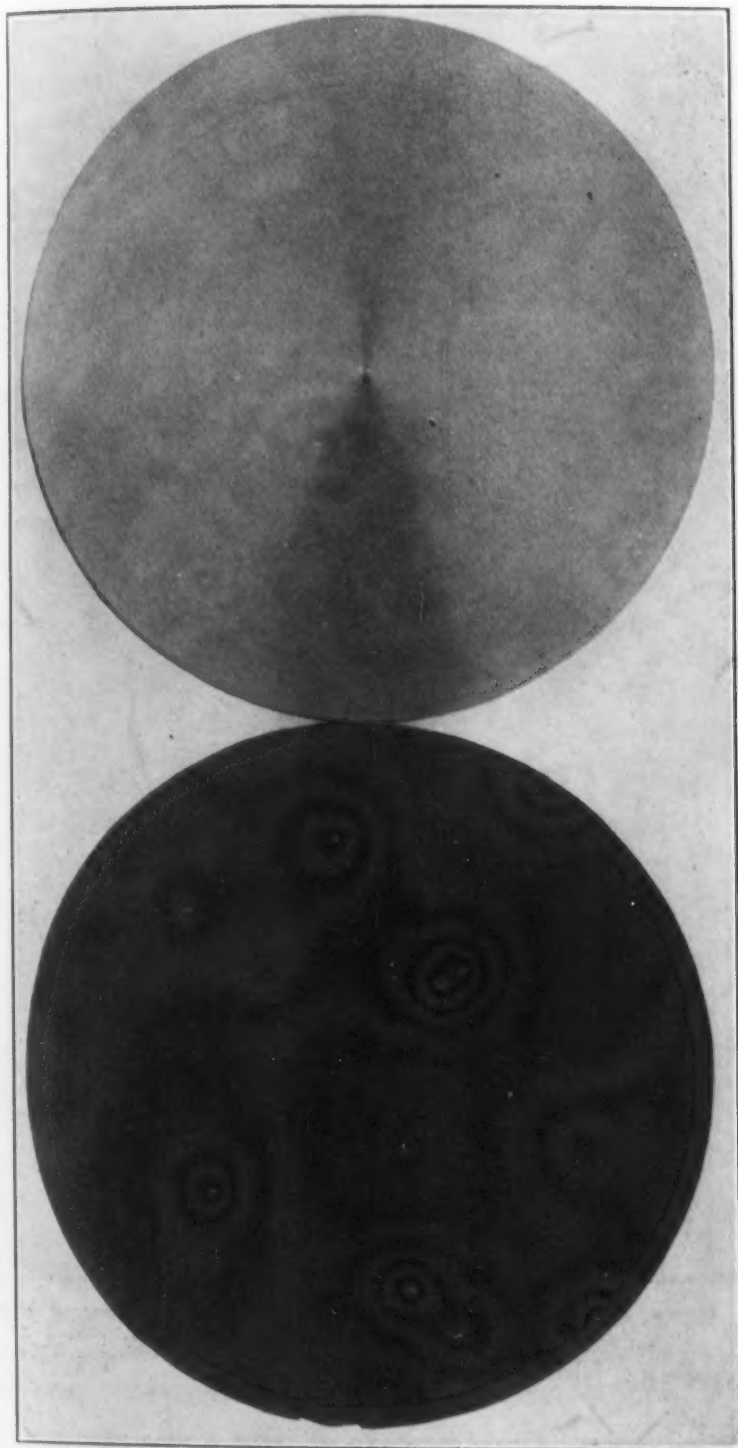


Fig. 21—Section of a Bar of Good High Speed Steel Before and After Etch Test. Diameter of Bar 3.5 Inches, Carbon 0.65 Per Cent, Tungsten 13.50 Per Cent, Chromium 3.95 Per Cent, Vanadium 0.93 Per Cent, Manganese 0.20 Per Cent.

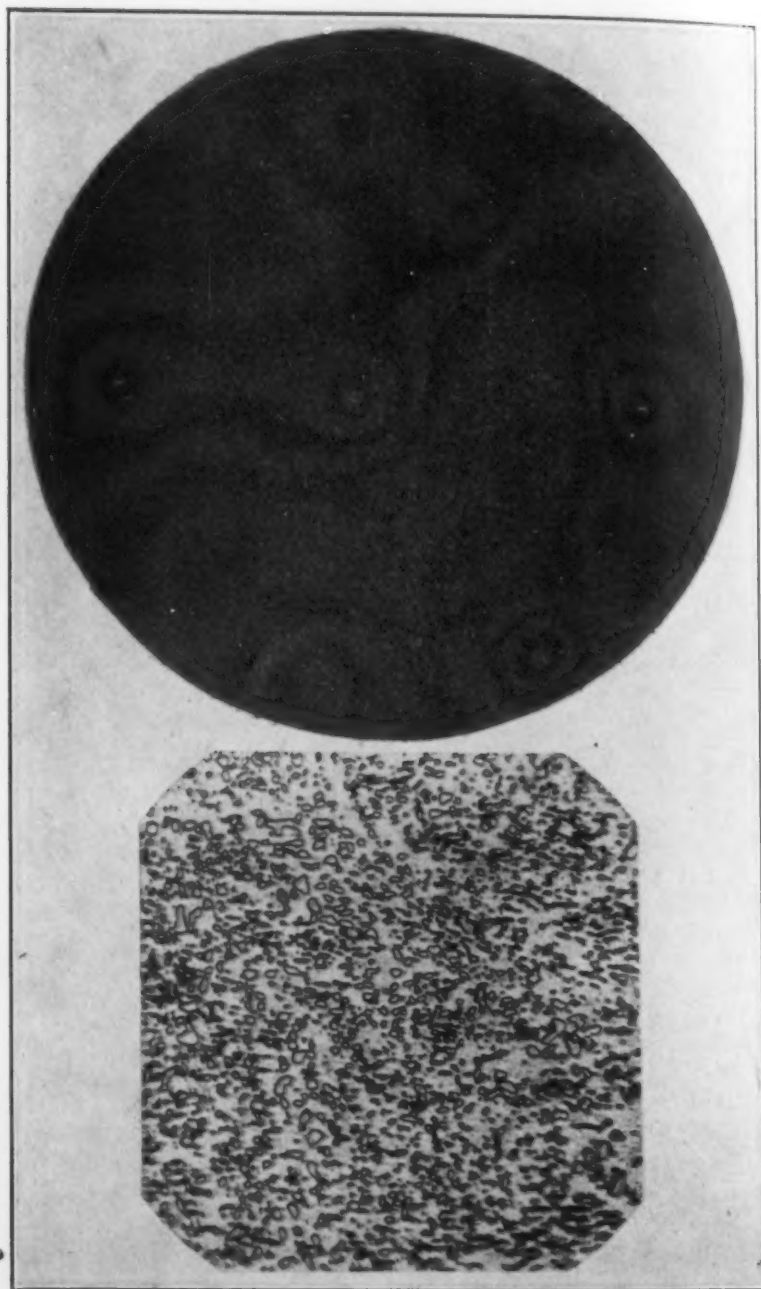


Fig. 22—Section of a Bar of Good Steel. Upper Photomicrograph After Etch Test. Lower Photomicrograph Magnification 500x, Etched in 1 Per Cent Nital. Diameter of Bar 3.5 Inches, Carbon 0.93 Per Cent, Manganese 0.27 Per Cent.

at 700 degrees Fahr. The material subjected to hot acid test, therefore, should be first carefully and thoroughly annealed.

1927

Er
For
divided
. 1.
tinuity
non-met
type of

for ge
parts
numer
either
of defe
the de
before
T
defect
withou
best in
steel o

ETCH STRUCTURES AND THEIR PERFORMANCE IN SERVICE

For convenience, structures revealed by deep etch test can be divided into the following types:

1. *Structures showing obvious defects or physical discontinuity in the metal.*—Cracks, pipes, seams, blow holes, scrap and non-metallic inclusions, are shown in Figs. 1 to 14. Obviously this type of structure cannot be depended upon in service, especially

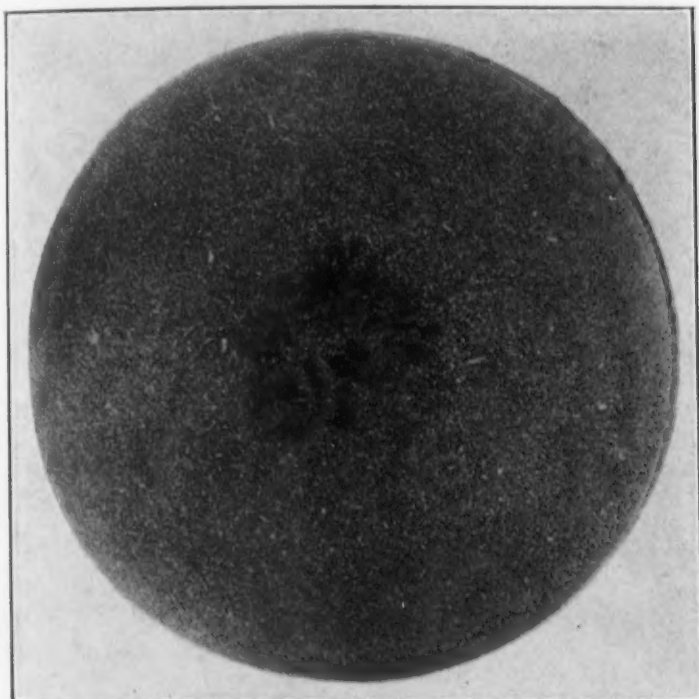


Fig. 23—Porous Structure in 1.00 Per Cent Carbon Steel.

for general tool work and for structural members and machine parts requiring strength and safety. The writer has come across numerous examples of this type of defects which have caused failure either in heat treatment, or in service. A great majority of this kind of defect can hardly be noticed on finished or machined surfaces and the deep etch test is an invaluable method of testing to disclose them before the material is made up into tools and machine parts.

The discussion of the original cause of this and other kinds of defects in steel is beyond the scope of this paper, but their presence, without doubt, is a direct offspring of faulty mill practice; and the best insurance that the consumer can take out against the defective steel of this type is the application of some sort of etch test on in-

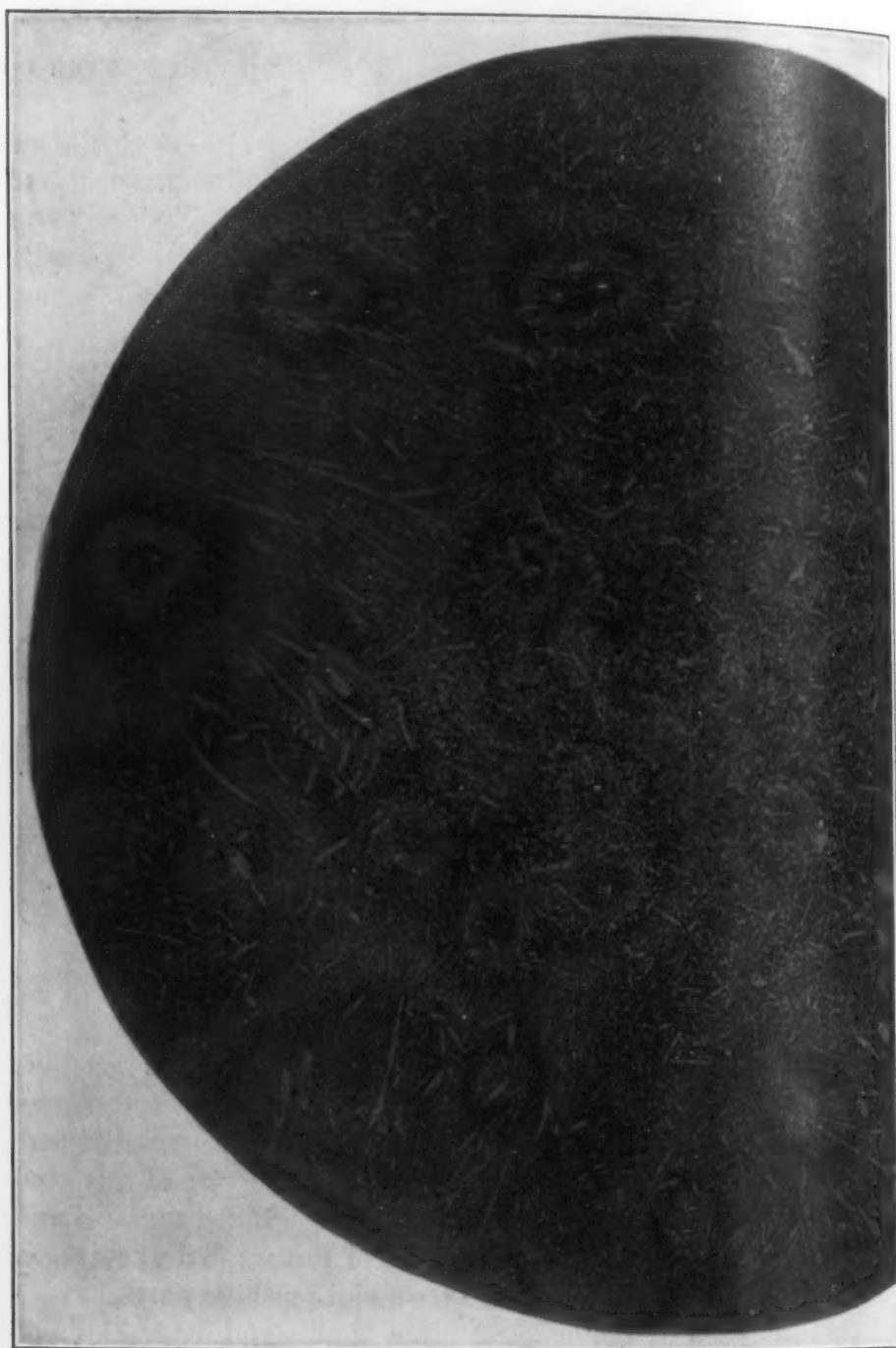


Fig. 24—Dendritic Structure in High Carbon Tool Steel. Diameter of Bar 6 Inches, Carbon 1.07 Per Cent, Manganese 0.43 Per Cent.

coming
fect in

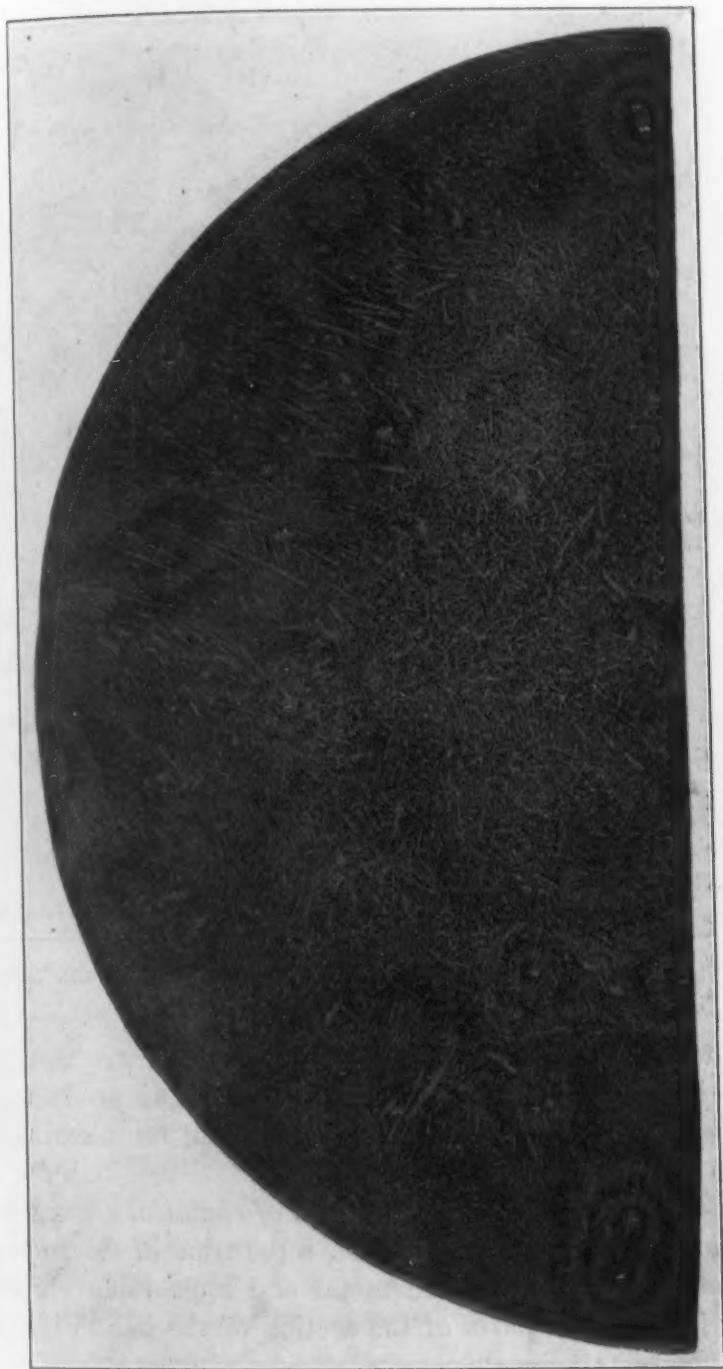


Fig. 25—Half Section of Dendritic Bar 0.90-1.00 Per Cent Carbon Steel.

coming material. It is true that the percentage of this class of defect in the tool steel made at present is considerably less than the

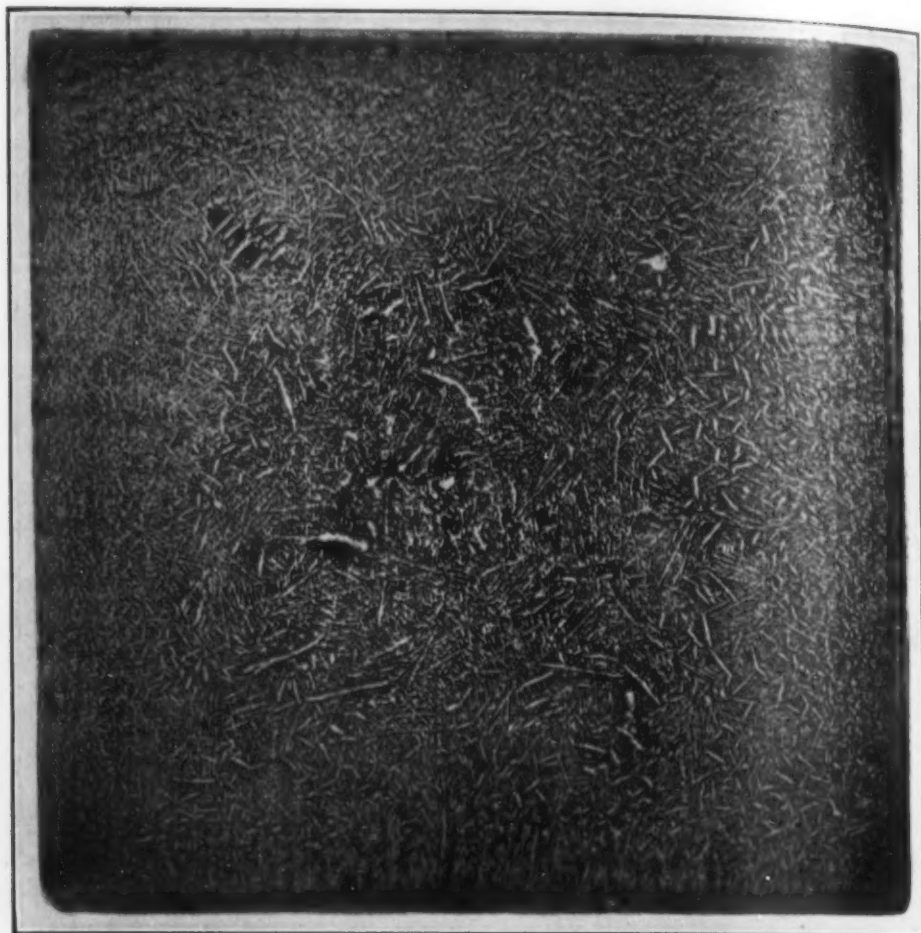


Fig. 26—Photomacrograph of Dendritic High Carbon Tool Steel, 4.75 Inches Square. Cross Section of Original Bar.

steel made nearly a decade ago, even several years ago, yet the existence of these defects alone in the present day product justifies the maintenance of such a relatively simple but most useful method of inspection.

2. *Structures showing segregation of chemical elements.*—This is a type of structure which shows the separation of elements during the solidification of the molten metal and appears in various outlines and in different parts of the section of the bar (Figs. 15-19). Like the non-metallic inclusions referred to in the preceding paragraph, the exact nature of the elements segregated, cannot be identified by deep acid etch. For that purpose specific reagents should be applied, supplemented by chemical and microscopic examination.

Serious segregations, as the term implies, are objectionable,

Fig.
Steel Sl
Hammer
to 1.5 I

while
sidered
prima
decisi
steel s
There
segreg
be che

3

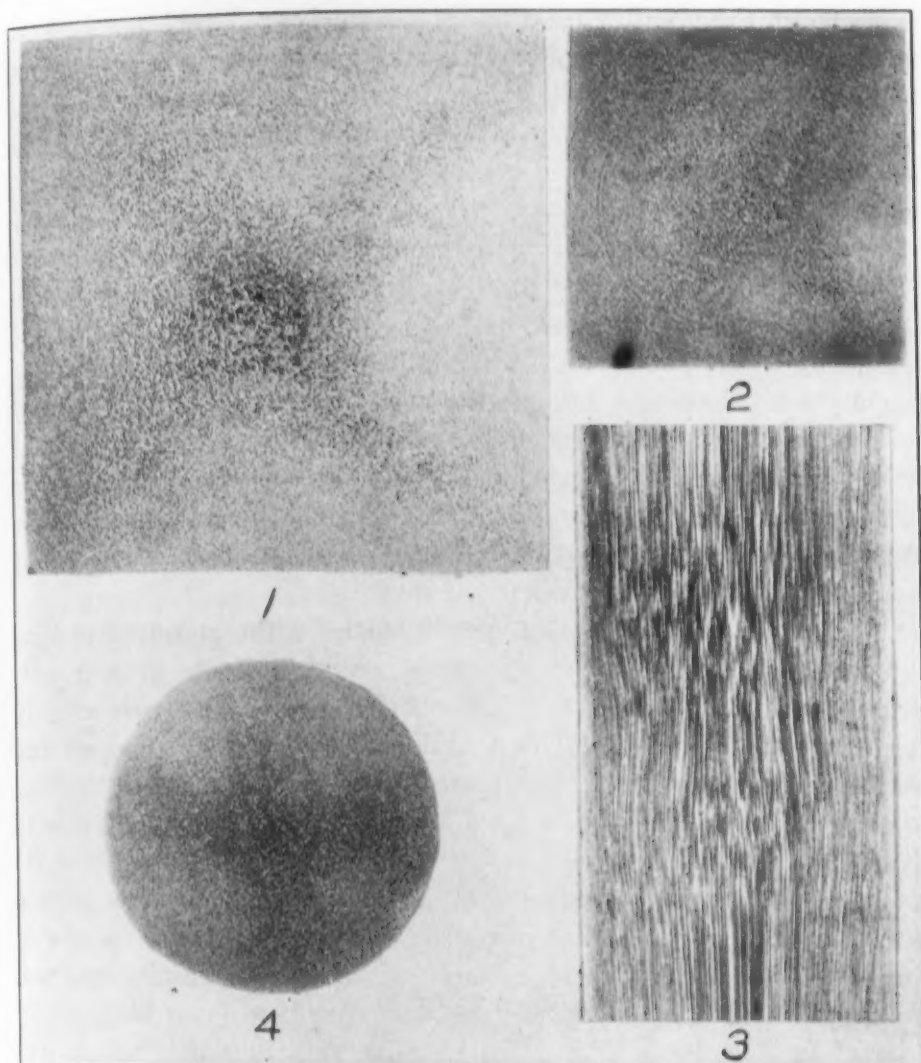


Fig. 27—Effect of Reduction of Area on the Dendritic Structure of High Carbon Tool Steel Shown in Fig. 26. (1) Same Bar Hammered to 2.5 Inches Square. (2) Same Hammered to 1.5 Inches Square. (3) Longitudinal Section of No. 2. (4) No. 1 Hammered to 1.5 Inches Diameter. Carbon 1.09 Per Cent, Manganese 0.36 Per Cent.

while the segregations of less serious nature can hardly be considered as sufficient cause for rejection. This last statement is based primarily on the fact that, first, it is quite difficult to distinguish decisively on the degree of segregation; second, tools made from steel showing segregation to certain extent, have given good service. Therefore, great care should be exercised when the presence of segregation is being considered as a basis for rejection, and it should be checked up by actual service records.

3. *Dense appearing structure.*—This type of etch structure is

subject to the modifying factors formerly referred to, such as method of manufacture, chemical analysis, heat treatment, amount of reduction, etc. (Figs. 20-22). Therefore, without knowing something of the history of the steel the appearance of the steel should not be taken as *prima facie* evidence of quality. Of the two pieces manufactured by the same process with practically the same chemical analysis and hardness if one shows smoother and denser looking etch structure, the probability is that it is a better steel in the great majority of cases, but this is not an absolute proof, and it is an important point to look out for when one is not in a position to couple his deep etch test results with both microscopic check and service test. A smooth and dense etch structure indicates the steel being free from defects visible to the eye, but beyond that one is likely to go into dangerous ground. A smooth and dense looking etch structure, therefore, should be taken more of an indication of sound structure than a measure of quality.

4. *Porous appearing structure.*—Under the standard etching conditions porosity of the structure would indicate greater non-homogeneity of the steel. This condition is met with primarily in the central portion of the bar, and often is related to piped and segregated centers (Fig. 23). Excessive porosity should be objected to, but we have here again a condition where we are not able to draw the line of demarcation between excessively porous and relatively less porous structure, and the question becomes then a matter of compromise. The purpose for which the steel is to be used should be given due consideration and the actual results obtained in service with a given type of porous structure must be borne in mind. In Fig. 23 is shown a disc with porous center which was made into a drawing die. Results obtained were favorably comparable to the results obtained from dies made of similar steel with non-porous center. There is no doubt, however, that a porous center indicates chemical segregation to a greater or less extent and the fact that the occurrence of porous structure is less common than relatively denser structure, and, furthermore, since this condition is encountered very much less in some mill products than others, it is concluded that it is more of a question of mill practice than anything else.

DENDRITIC STRUCTURE

There is a good deal written and spoken about this type of

struc
need
noted
show
steels
From

1927



Fig. 28—Dendritic Carbon Steel Drill.

structure, as to its origin, distribution and its elimination which need not be discussed here (Figs. 24-30). Dendritic structure was noted in small as well as in large bars. High carbon steels seem to show greater tendency to be dendritic than low carbon steels, alloy steels less than the carbon steels, and the high speed steels the least. From the standpoint of manufacture there is not much to choose

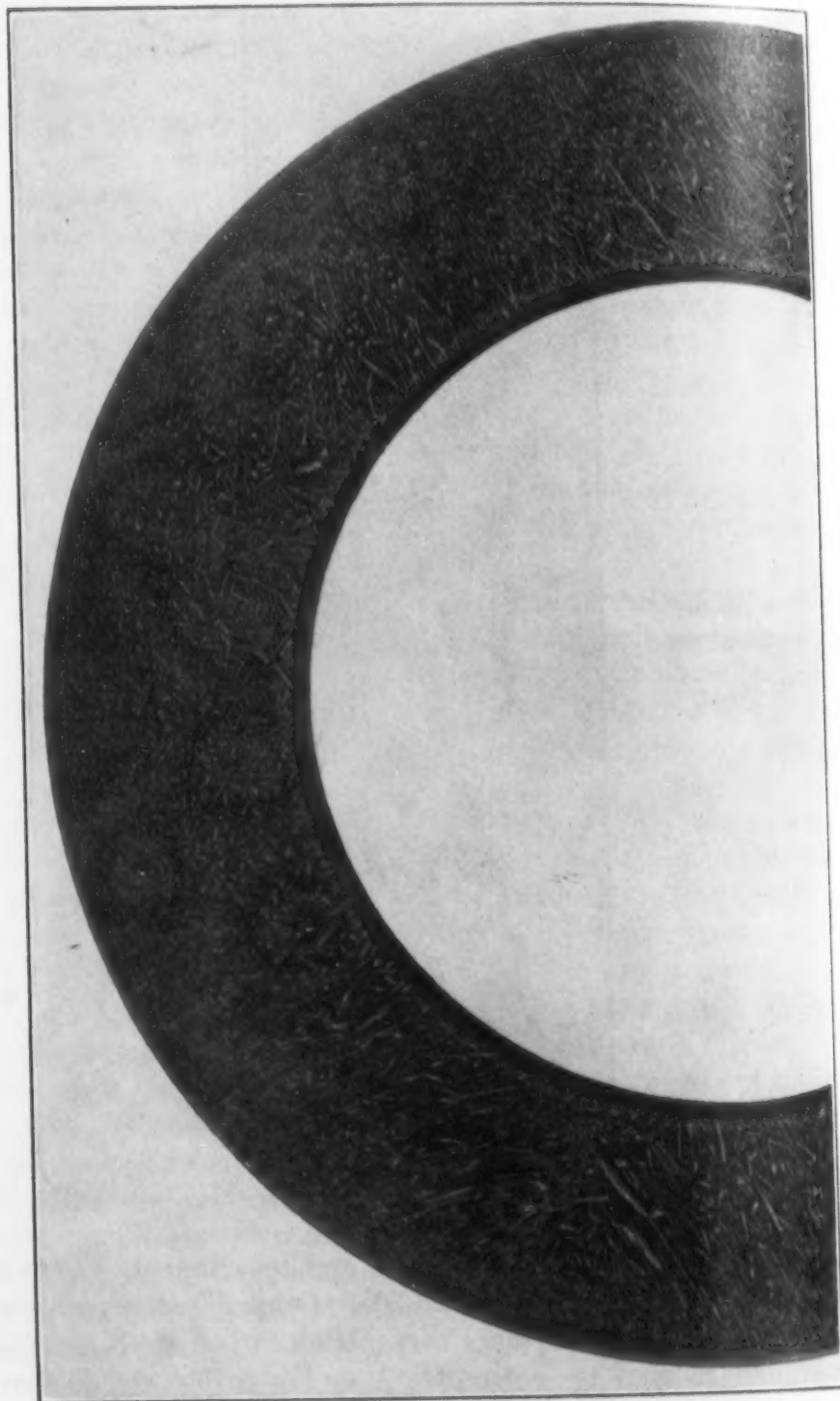


Fig. 29—Drawing Die Made from Dendritic Carbon Tool Steel After Etch Test. Diameter of Bar 8 Inches. Diameter of Die 7.5 Inches. Carbon 0.91 Per Cent, Manganese 0.30 Per Cent.

between
there are
when the
that it
Priestly
dritic s
molten
the ten
N
structu



Fig.
Cut from

up a
per c
fore
up b
elim
when
tudi
redu

hap
to b
cry

between the crucible and electric and open-hearth methods, although there appears to be a slightly less tendency to dendritic structure when the steel is made in the open-hearth; but the indications are that it is directly related to mill practice. Careful tests made by Priestly have shown that the occurrence and the elimination of dendritic structure is primarily a question of the rate of cooling of the molten steel in the molds. The slower the cooling, the greater is the tendency to dendritic growth.

No method of ordinary heat treatment will eliminate dendritic structure. Normalizing has no effect on it. Giolitti had to heat

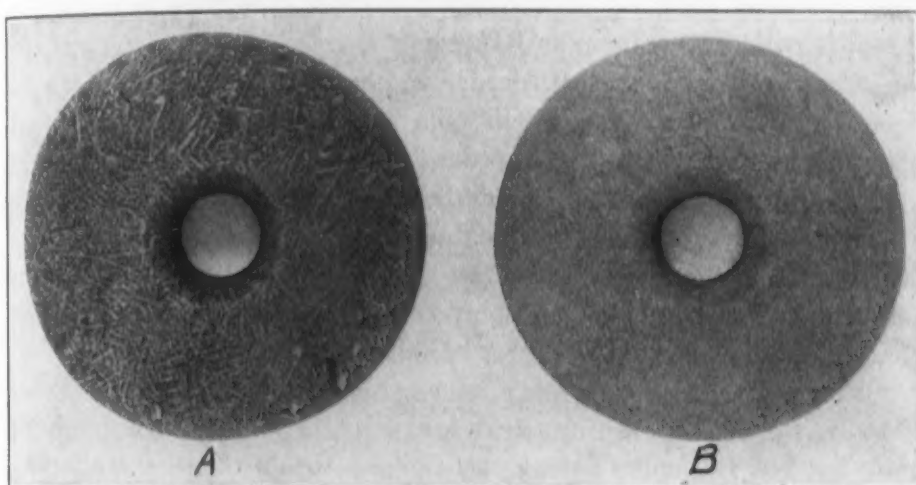


Fig. 30—Drawing Dies Made from Dendritic and Non-Dendritic Carbon Tool Steel. Die A Cut from a Bar 6 Inches in Diameter. Die B Cut from a Bar 2.25 Inches in Diameter.

	Carbon	Manganese	Phosphorus	Sulphur
A	1.26	0.36	0.021	0.029
B	1.21	0.49	0.023	0.012
Rockwell Hardness—each 66				

up a dendritic nickel steel containing 0.42 per cent carbon and 2.02 per cent nickel to about 2000 degrees Fahr. a good many hours before he succeeded in breaking up the dendrites. They can be broken up by hammering to sufficient reduction, but cannot be altogether eliminated. Such hammered pieces will appear free from dendrites when etched on their transverse section, but if etched on the longitudinal section will show finely elongated dendrites. The effect of reduction by hammering on the dendrites is shown in Figs. 26-27.

Among the etch structures, dendritic structure has been perhaps the most disputed one as to its service value. This appears to be based mostly on the view that dendritic structure is due to the crystalline segregation of chemical elements in steel. In other

words, the dendrites have a chemical composition different than the ground mass in which they are found. This is caused by the first solidification of the elements of higher melting point, which makes the ground mass or the fillings between the dendrites richer in carbon, phosphorus and sulphur. After the solidification, however, carbon diffuses itself, making the carbon contents of the dendrite and fillings the same.

It is also stated that the subsequent operations, although destroys the crystallographic unity of the dendrites, the chemical non-homogeneity remains the same. Therefore, it is further concluded that if a steel showing excessively dendritic structure is made into a tool it will not perform satisfactorily.

To what extent this difference in chemical composition obtains, is not known. In other words, the actual percentages of carbon, phosphorus and sulphur in the dendrites and the fillings cannot be told definitely. Analysis of dendrite scrapings by others and the writer has not shown any noticeable difference in the chemical composition of the dendrites and the ground mass. The effect of the actual difference in chemical composition on the working properties of the dendritic steel, therefore, becomes still more indefinite.

The writer, however, has observed the performance of hundreds of tools, for cold stamping, drawing, cutting, made from dendritic steel, but has not come across any serious trouble with their failing prematurely.

In Fig. 29 is shown a cut and draw die made from dendritic steel, which was in service over three years, with repeated shrinking and grinding and gave satisfactory results. In Fig. 28 is shown a $\frac{7}{8}$ -inch twist drill and is one of the many that gave satisfactory results.

In regard to the relative service values of dendritic steel and a steel of practically same analysis, but almost wholly free from dendrites, there is not sufficient experimental data yet. A limited number of experiments made by the writer for drawing dies showed no appreciable difference in performance. In Fig. 30 is shown two drawing dies, which were given same heat treatment and were tried on drawing copper and brass tubing. There was no noticeable difference between the two from the standpoint of number of pieces drawn, finish and wear per foot of tubing drawn.

SUMMARY

A relatively simple means of detecting unsoundness or serious segregations in steel and iron before much time and money has been spent on them, is of vital importance to the consumer of steel. Deep etch test is a most useful method to reveal such defects. It does not always reveal the exact nature of the defects in the metal, but so long as it reveals their presence, it serves the main purpose for which it is used. But if it is applied beyond detecting discontinuity in the metal and serious segregations, it is liable to abuse and misinterpretation, this, however, in no way detracts from the value of the method.

To secure consistent results and to properly interpret them, the strength and the temperature of the etching acid, the time of immersion should be standardized and the other factors that are given in this paper, which influence the results, must be given due consideration.

DISCUSSION

Written Discussion: By Gregory J. Comstock, Director of Research, Firth-Sterling Steel Co.

Mr. Keshian's paper is not only excellent but it is extremely timely.

The test which he describes is being widely applied at present and is used as a basis for the acceptance and rejection of iron and steel.

There is no doubt that the deep etch test when applied to tool steel (to which I must limit my remarks) affords an opportunity for the rejection of unsound material which in many cases would otherwise escape detection and result in tools which would give an inferior production. It has therefore been welcomed by the conscientious manufacturer of high grade steels as a means of amplifying the tests which he previously had at his disposal for detecting unsound material before it leaves his works. Discriminating users of steels have applied it as a means of protecting themselves against loss from the very inception of the test. It has filled a long felt want and has already taken prominent rank among industrial inspection processes. There is no doubt that thousands of dollars have already been saved by the deep etch test.

However, as is generally the case when a new test of this kind is introduced the prevailing tendency has unfortunately been to endeavor to obtain more information from it than it can consistently afford. As Mr. Keshian has clearly pointed out it has its limitations as well as its advantages. It would seem therefore that the necessity exists for a further study of this test in an effort to, first, define its limitations by a clear understanding of the mechanics which are involved, and, second, to amplify its usefulness by the same means.

I think it is significant that, in summing up the conclusions, he has been able to derive from the thousands of tests which have been painstakingly conducted under his direct observation, Mr. Keshian has said, "if the deep etch test is applied beyond detecting the discontinuity in the metal and serious segregations, it is liable to abuse and misinterpretation."

It has been my experience that when a piece of tool steel is immersed in warm acid and the attack permitted to continue for a considerable time before the steel is removed for examination changes in the appearance of the piece take place from some of which it is possible to draw conclusions as to its suitability for use and some others from which it is at present not altogether safe to draw any positive conclusions as the action producing them is not thoroughly understood.

If the test is to be a fair one rejection or acceptance must be based on a definite knowledge as to what these changes in appearance indicate and limited to indications concerning which there is no doubt as to the effects which they will produce.

Certain defects which are more or less common to tool steel are sharply defined and most positively indicated by deep etching if the test is properly conducted. These are:

1. Piped steel
2. Seamy steel
3. Excessively decarbonized steel
4. Steel which has been injured in hammering or rolling
5. Steel which has not been properly melted.

There is no doubt whatever that steel in which these defects occur should not be used for expensive tools and dies. The presence of these defects are clearly indicated by the deep etch test which renders them optically apparent in an easily understandable manner. The defective conditions which we have enumerated are known to produce injurious results. Rejection therefore based on the presence of these defects as disclosed by properly conducted deep etching is clear cut and decisive. No reputable steel manufacturer wishes to sell steel in this condition and will not hesitate to replace steel which is definitely shown to be unsound for these reasons. If the deep etch test were to be used to determine only these facts, as it is in some cases, there is no doubt that it would be welcome to every one concerned as a logical basis for protecting both the manufacturer and the consumer against dissatisfaction and poor production results.

The appearance of the deep etched pieces is sometimes interpreted as indicating other defects some of which Mr. Keshian has mentioned. A few of these are:

1. Structures showing the segregation of chemical elements
2. Porous appearing structure
3. Dendritic structure.

I would call your attention to the fact that Mr. Keshian, speaking

from his considerable experience, sums up the importance of these defects in the following way:

With regard to segregations Mr. Keshian says: "—segregations of less serious nature can hardly be considered as sufficient cause for rejection."

With regard to porosity Mr. Keshian states: "—we have here again a condition where we are not able to draw a line of demarcation between excessively porous and relatively less porous structure and the question becomes a matter of compromise."

Mr. Keshian's remarks on dendritic structure are: "The writer, however, has observed the performance of hundreds of tools for cold stamping, drawing, and cutting made of dendritic steel but has not come across any serious trouble with their failing prematurely."

There is no doubt that the indications of the presence of these last mentioned conditions which are developed by the deep etch are not always as clear cut and decisive as one could wish nor that the effects of variations in manipulation or preparation of the specimens are most pronounced. All of these conditions if accurately indicated by the test and correctly interpreted by the investigator must be considered to be of less importance in the effects they will produce than the ones first mentioned.

The mechanics involved in the action of the acid in magnifying tiny inclusions of microscopic proportions until they become optically apparent; the development of evidences of the cast structure during the test; the etching action of the acid on the structure which must exist in the annealed condition and many more phenomena which take place are neither easy to understand with our present knowledge on this subject nor easy to transpose into practical statements of the effects which the structures actually have on the tool. On the whole the etching action of the acid can not be considered to be as thoroughly understood as could be wished and the finer interpretation of the results of such an etch are still a matter of conjecture and some controversy.

As a result of this fact I have personally preferred to harden and break a section to determine the finer points involved in the suitability of the steel which has passed the deep etch test in that none of the more important structural defects appeared. There may be cases, however, where some rather indecisive indications of a defect can be directly coupled with the consistent failure of an individual tool and in such cases it should be obviously taken as a basis of rejection and a steel of a special character required.

It is certainly not my desire to impose limits on this test which do not exist nor to cast a doubt on the advisability of using it to detect injurious defects. I do feel, however, that its general use at the present time should be limited only to the detection of such defects as are known to produce unsatisfactory results and which are positively indicated by the test in a manner which is thoroughly understandable and beyond controversy.

This test is, in my opinion, too valuable to chance casting discredit upon it by overestimating its present value. I would like to suggest

for your serious consideration the advisability of using it as a means of discriminating against defects which it discloses in a positive manner in the light of our present understanding and at the same time of instituting a comprehensive investigation of the test to ascertain the possibility of further amplifying its definite disclosures.

Written Discussion: By Alvan L. Davis, Scovill Mfg. Co., Waterbury, Conn.

Any one who studies Mr. Keshian's admirable paper will realize that it is a valuable contribution to our annals. This paper embodies the sort of information that our Society was originally designed to secure and spread amongst its members.

Systematic inspection and testing of tool steel pays the user. The greater the value of the tools to be made, the more elaborate should be the testing of the steel before use. There are various ways of checking the quality of tool steel, apart from the basic test of use, which is liable to be in the nature of a postmortem. The deep acid etch is one way.

Plates 1 to 14, which illustrate the use of the deep etch test in detecting physical discontinuities (such as pipes, cracks, seams, blow-holes, and large sized inclusions) are a striking exhibit of what steel may be at its worst. It is rare to find such unsound specimens in steel nowadays, and moreover, such defects can be detected by other means, such as hardening and breaking a disc cut from the end of the bar, but this does not deny value to the deep etch test. It affords insurance against such palpable physical defects.

When it comes to segregation of chemical elements, and to the difference between coarse or fine texture as revealed by the deep etched test, Mr. Keshian wisely cautions against drawing conclusions that are not based on service tests. However, when built upon the bedrock of service tests, a comparison of deep etched structure may prove valuable, though my own preference is for the longitudinal fracture of properly hardened test discs. Such hardened fractures show the difference between a deep and a shallow hardening steel, and also between a granular and procelainic structure after hardening. This is valuable to know.

Under the head of "Dendritic structure", a point which might be stressed more strongly is that the longitudinal section reveals this type of structure much more readily than does the transverse section. The "Dendritic structure" shown in Fig. 2 of Plate 27, is doubtless closely related to the "fibroid" or "woody" structure that appears in the longitudinal fracture of a test disc cut from a bar. (Though other causes than dendrites are at times partly responsible for woodiness.)

While there are forms of tools with which Mr. Keshian finds no disadvantage in the fibroid or woody structure, there are other such uses as solid heading dies and punches, where life is liable to be decreased, due to splitting.

Our Society is fortunate in receiving such a well-balanced paper, that promises to be of much value to our members.

Written Discussion: By L. A. Lanning, Bristol, Conn.

I wish at the outset to congratulate Mr. Keshian on the thoroughness

of his work along this line. He has apparently had an excellent opportunity to observe the advantages and value of this test in a wide variety of production requirements and has, I understand, rendered some very valuable service in the selection of bars of steel suitable for use.

Mr. Keshian has, I believe, carried this test out in much greater detail than the average operator and greater than is usually necessary.

In most cases it is desired to know whether or not a given piece of steel is fit for service. This involves the question as to service requirements: that is, whether the inside or center of the bar is to be used or whether the outside is to be used.

The center of the bar may be porous and badly pitted yet this bar may be entirely satisfactory for a hollow tool where the center portion is removed. The same applies to the surface. Where the defective portion is to be removed by machining the steel should not be condemned.

Examination by the deep etch method may thus serve as a guide for the selection of the proper bar for a given tool instead of a purely inspection method involving only the acceptance or rejection of the bar of steel in question.

I was quite interested in Mr. Keshian's remarks on dendritic structure. There is apparently some controversy on the effect of this condition on the service of the tool or its hardenability. I recall an instance of the cross-wise fracturing of four drop forge dies during hardening. All four of these dies showed a bad case of dendritic structure. I have always attributed the transverse cracking of these dies to this dendritic structure. I would appreciate any enlightenment on this subject.

Written Discussion: By V. O. Homerberg, Massachusetts Institute of Technology, Cambridge, Mass.

The author makes the statement that "if properly manipulated, the deep etch test has a wide field of application". Emphasis should be placed on the expression "if properly manipulated". So many instances of improper manipulation have come to my attention that I believe that the mention of certain precautions is justified.

First of all, the preparation of the specimens should receive careful attention. Many specimens are given the deep acid etch without any preparation after sawing. Localized streaks of highly strained material may be readily produced in this operation. These streaks generally etch faster and deeper than the neighboring metal. The surface of the specimens, therefore, should be finished on emery paper so that a uniform surface condition is obtained. An extreme case of an improper surface condition came to my attention a short time ago in which a shipment of steel was rejected after etching the fractured surface of the material.

A second error which is often made in applying this test is to leave the specimen in the acid for too long a time. The time of exposure to the acid has to be left to the judgment of the operator. I have seen cases where specimens have been left in the acid for six hours where an exposure for a half hour would have sufficed. Satisfactory results cannot be obtained on prolonged etching. A perfectly satisfactory steel after a long exposure to the etching reagent may appear to be very unsatisfactory.

Undoubtedly, the most important factor in the use of the deep etch test is the proper interpretation of the results. I firmly believe that in many cases it is just as difficult to correctly interpret the results of this test as those observed on microscopic examination. I have observed cases in which tool steel has been rejected after showing only a trace of sponginess in the center. In one instance such a lot of steel was to be used for making milling cutters in which case the center of the bar containing the slight sponginess was removed. The determination of the line of demarcation between acceptable and non-acceptable steels requires both judgment and experience. The purpose for which the steel is intended must be given proper consideration.

The author states the case correctly when he calls attention to the fact that in a great many instances the defects are so obvious after deep etching that there can be no doubt as to unsoundness and inferiority of the steel, but that the test loses greatly in simplicity and dependability as these defects become less pronounced.

The author calls attention to segregation in steel bars as indicated in Fig. 17. I have encountered cases on etching which have shown zones similar to that exhibited in the upper part of Fig. 17, in which a microscopic study failed to show any indication of unsatisfactory material. A research metallurgist of one of the large steel companies informed me that he had made a study of this phenomenon and found that it was often due to the jarring of an ingot while in the process of solidifying. The boundary of the two zones was considered as the line of demarcation between that part which had solidified and the liquid portion which was put into motion as the result of the jarring action. However, it is true in most cases, that zones of this character represent marked segregation, as stated by the author.

Generally, it has been considered that the presence of a dendritic structure in steel bars is an indication of defective material. I am glad to note that the author has encountered many cases where tools showing such a structure did not give inferior service results. I can confirm this observation as I have noted such a structure in a number of tools that were subjected to severe service conditions and gave excellent results. Here again, the presence of a dendritic structure in steel bars, especially in the smaller sizes, may not be desirable but its presence does not necessarily offer a basis for rejection.

I am well acquainted with the work of the author in applying the deep etch test and I am sure that if every inspector of steel would use as much care in applying the test as he does, there would be no necessity for the emphasis on the precautions which I have mentioned.

Written Discussion: By G. V. Luerssen, Carpenter Steel Co., Reading, Pa.

While the deep etch test is undeniably as valuable means of detecting material defects in steels, as Mr. Keshian points out the results of the test are often open to wide degrees of interpretation. Where the defects revealed by etching are very marked, such as in the case of actual pipe, internal cracks, large inclusions of foreign material, etc., there can be no question of inferiority. Where such conditions as segregation, small non-

metallic
different
less deg
determin
impair t
well est
records.

Of t
hydroch
of etch
solution
suggeste
momete
results
work th
for a s
found

Mr
are ent
we hav
respons
analysis
mass, a
serve t
test, in
result
section

Th
the et
in pro
small
creasin
are dra
that a
of the
chloric
resulti
sion c
develo
the b
larger
porosi
T
it a
requir
pointi
will o
tion c

metallic inclusions and dendrite patterns are evidenced, however, a very different problem presents itself. These conditions occur in a greater or less degree in all steel, and we are thus confronted with the question of determining whether or not they are of a degree and character which will impair the life of the finished part. To do this intelligently requires a well established background of experience based on actual performance records.

Of the etching reagents described in Mr. Keshian's paper, half strength hydrochloric acid is undoubtedly the most commonly used. The intensity of etch obtained in this acid is affected greatly by the temperature of the solution. If the temperature is to be held just below the boiling point, as suggested by Mr. Keshian, it should be carefully controlled with a thermometer, and a uniform temperature should be adopted if comparative results are to be obtained. It has been our experience that for general work the better method is to keep the solution at the boiling point and etch for a shorter length of time. An etching time of 20 minutes has been found satisfactory.

Mr. Keshian's remarks on dendritic structure as applied to tool steel are entirely confirmed by our experience over a number of years in which we have never found dendritic patterns as revealed by etching to be responsible for tool failure. Nor have we been able to detect by chemical analysis any difference in composition between the dendrites and the ground mass, although a very slight difference undoubtedly exists. These facts serve to emphasize the very high magnifying power of the deep etch test, in which very slight variations in composition occurring as a natural result of crystallization are brought out in sharp contrast on the etched section.

This magnifying property is also quite marked in connection with the etching out of sulphides and other non-metallic inclusions. Sulphur in properly made steel occurs as globules of manganese sulphide, very small in size at the surface of the ingot where cooling is rapid and increasing in size toward the axis where cooling is slower. These globules are drawn out into strands in the process of working the ingot into a bar so that a section of the bar at right angles to the axis will cut a great number of these sulphide strands. Manganese sulphide is readily soluble in hydrochloric acid, but not only is the sulphide dissolved out in etching; the resulting pit is greatly enlarged, so that a very minute sulphide inclusion distinguishable only at 500 magnifications under the microscope develops into a pit often visible to the naked eye. Toward the axis of the bar where the inclusions are larger, the pits are correspondingly larger, and after prolonged etching may very readily be mistaken for porosity.

Thus, while the magnifying property of the deep etch test makes it a very valuable tool, this same property also makes it a tool which requires skill in handling. The Society is indebted to Mr. Keshian for pointing out many of the pitfalls, and it is to be hoped that this paper will open the way for a better understanding and an eventual standardization of this method of test.

Written Discussion: By H. S. Rawdon, senior metallurgist U. S. Bureau of Standards.

The use of deep etch test for the examination of iron and steel antedates our present methods for the study of the microstructure by a good many years. With the development and application of the microscopic methods the study of the macrostructure by the deep etching of large sections was relegated somewhat into the background, but the past few years has witnessed a greatly renewed interest in the deep etching method, so that today in a good many shops this test is always taken into consideration in the acceptance of any purchase order of steel.

The author of this paper has made a distinctly valuable contribution in the compilation of the various etching reagents which may be used and the discussion of other conditions which may affect the results of the test. In the opinion of the writer, however, this service would have been still more valuable if typical macrographs of the same types of steel had been given to show the relative advantages and limitations of the different reagents.

One point brought out by the author which is of particular interest to the writer is the discussion of dendritic steel. In some of the alloy steels, particularly those containing nickel, this structural feature is often found. After certain etching methods this appears to be such a prominent feature of the structure that one naturally considers such a steel as having properties distinctly different from those of a steel free from this structure. Usually the presence of dendrites is considered as rendering the steel somewhat inferior in its general mechanical properties to a similar steel in which this feature is absent. The author's observations on the service performance of tools and dies for the shaping and working of metals indicates, however, the presence of the dendritic structure in itself is not necessarily a mark of inferiority, at least in service of that kind. It would be of decided interest to learn whether these observations of the author's are confirmed by the experience of other metallurgists, both for this and for other kinds of service.

The author is to be congratulated on the many fine macrographs he has given in the paper. In a method as old as deep etching, of course, there is very little, if anything, really new, that can be shown in such macrographs. All of the readers who have had experience along this line will recognize what are almost exact replicas of many of their own specimens. For the education of some of the students of metallography the series is well worthwhile, however.

Written Discussion: By N. B. Hoffman, metallurgist, Colonial Steel Company.

Mr. Keshian's paper on the deep acid etch test is very well written and shows much effort on his part in its preparation. In preparing a paper on a subject of this type, much of its value depends upon the illustrations used to illustrate the point in question. This, Mr. Keshian has done very forcibly.

There is no question in my mind relative to the value of the deep acid etch test. This test, to be of any great value, must be performed by

1927

an operator familiar with the subject and capable of determining from experience just which structure is good and which is bad. As for example: A number of operators have rejected steel on the deep acid etch test showing any dendritic structure. Mr. Keshian says that a die containing dendritic structure shows equally as good performance as one made from a steel free from such dendrites.

In acid etching the steel, to successfully bring out its true condition, much depends upon the method of etch, as well as the etching solution used. In performing this work today, you will find any number of solutions and combinations used. The temperature of the etch solutions and the time of immersion in the solution itself has a great influence on the ultimate result.

The acid etch test is abused in a number of instances. I know of one metallurgist who bought his steel subject to the acid etch test. He had three sources of supply and should he need two bars of steel, he would order two bars from each of his three sources of supply, acid etch the six bars and accept the two best bars of the six, rejecting the other four. This method of inspection I am sure all will agree is quite wrong. Therefore, if the deep acid etch test is to become of any general value, it will be necessary to set up some standard of rejection, as well as a definite method of etching.

Author's Reply to Written Discussions

I feel deeply gratified by the favorable comments which this paper has received, and I wish to especially thank the authors of the written discussions for their valuable and complimentary remarks.

Almost all of the points brought out by the authors of the written discussions, as to the value and the shortcomings of the deep etch test, are confirmative of what I have already stated in the paper. Therefore, there is very little that I can add to that part of the subject. While I am aware of the abuse and misapplications of the method, I feel that this abuse and misapplication is not peculiar to deep etch test alone. It was true and has been true for all other methods of testing before they were standardized. Likewise the deep etch method must pass through a period of transition and seasoning, so to speak, before it is standardized, and the sooner its standardization the less will be its abuse and misapplication. From this standpoint there is, apparently, a unanimous opinion among those interested in the matter as to the necessity of this standardization, which should include the strength of the etching solution, the temperature and the time of etching.

Referring to some of the particular points brought out in the discussion, Mr. Davis suggests the use of fracture test, also Mr. Comstock, where the results by the etch test do not appear to be decisive. I am afraid, however, that we will encounter similar trouble as the factors which influence the result of etch test also effect the fracture of the steel. The temperature, the thickness of the sample and the analysis of the steel will have to be very carefully considered. There is a similar difficulty in drawing a line of demarcation between the porcelainic and velvety fracture. My experience has shown that the segregation can be more sensitively distinguished by etch test than by fracture test.

Mr. Davis also refers to the heading punches and dies made from dendritic steel being liable to cause failure in service. In the writer's experience these tools when made from fairly dendritic steel, up to 2 inches in diameter for cold heading brass and iron wire, have not given serious trouble. It is possible that dies and punches of larger diameters which undoubtedly will have a greater degree of dendritic structure than is possible with smaller bars, might split in service, yet cold stamping tools which are quite similar in the punishment they receive in service, when made from excessively dendritic structures did not fail.

Answering Mr. Lanning's question as to the effect of dendritic structure on the cracking of tools in hardening, I have particularly noted the behavior of tools made of dendritic steel in hardening and have failed to establish a connection between the failure of this type and the dendritic structure. The die shown in Fig. 29 after being in service a long time was hardened in brine, eleven times, with annealings between each hardening to see if it would crack, but it did not.

I am afraid that Mr. Luerssen sees the difficulty of interpretation of the etching results on a greater scale than it really is. The etch test will show inclusions and minor segregations. Whether this condition should be considered a basis for rejection surely cannot be decided by mere opinion of the inspector and the actual service test as he suggests himself should be the final judge. I am glad to know that his experience with dendritic structure confirms my own.

CARBURIZING IRON BY MIXTURES OF HYDROGEN AND METHANE

By W. P. SYKES

Abstract

This paper describes the determination of mixtures of hydrogen and natural gas (80 per cent methane) neutral to a steel of given carbon content at temperatures between 1470 and 2085 degrees Fahr. (800 and 1140 degrees Cent.). The observed concentrations of CH_4 in the atmosphere correspond closely to the theoretical values previously suggested by Le Chatelier.

The carburizing action of various mixtures of hydrogen and natural gas on armco iron at different temperatures is described.

IN order to control the carbon content of a proposed series of ternary iron-carbon alloys it seemed desirable to supply the carbon by heating the metal in a carbon-bearing gas. An atmosphere neutral with respect to a given carbon content in the alloy, was another objective in order to permit prolonged heating at temperatures as high as 2552 degrees Fahr. (1400 degrees Cent.)

The decarburizing action of hydrogen on steel at elevated temperatures has been described by Campbell¹. In a discussion of this paper Le Chatelier wrote in part as follows:

"Taken as a whole, the results obtained confirmed the old experiments of Forquignon so far as the elimination of carbon and of sulphur by hydrogen were concerned. That scientist showed that carbon was eliminated in the state of methane, CH_4 . At the temperature of 1832 degrees Fahr. (1000 degrees Cent.) equilibrium between the hydrogen, methane, and free carbon corresponded with a mixture containing about 1 per cent of methane and 99 per cent of hydrogen. That limit would remain the same in the presence of a steel saturated with carbon, that is to say, containing, at about the temperature of the experiment, 1.75 per cent carbon. For non-saturated steels the proportion of methane would

¹E. D. Campbell—On the Decarburization of Steel with Hydrogen. *Journal, Iron and Steel Institute*, 1919, No. II.

A paper presented before the ninth annual convention of the society held in Detroit, September 19 to 23, 1927. The author, W. P. Sykes, is metallurgical engineer, Cleveland Wire Works, Incandescent Lamp Department, General Electric Company, Cleveland. Manuscript received July 14, 1927.

decrease with the percentage of carbon, and practically in direct proportion with the latter. In other words, in the case of steel containing 0.15 per cent of carbon, the percentage limit of CH_4 in the mixture would be 0.1 per cent. It would be seen that a very considerable excess of hydrogen would be required to eliminate the whole of the carbon.

"An interesting experiment would be to treat steels with variable percentages of carbon with prepared mixtures of hydrogen and methane in, for example, such proportions as 1 per cent, 0.5 per cent, and 0.1 per cent of methane. It would undoubtedly be found that some steels would not have been decarburized and that others, on the other hand, would have been carburized."

A later paper² by Campbell, Fink and Ross, describes experiments in which four steels of different carbon content were heated in an atmosphere of hydrogen for several days at 1742 to 1760 degrees Fahr. (950 to 960 degrees Cent.) At the end of this time all four steels were found to have approximately the same carbon content. The high carbon steels had lost carbon and the low carbon steels increased in carbon content.

Temperatures between 1292 and 2552 degrees Fahr. (700 and 1400 degrees Cent.) are conveniently attained in a tungsten-wound resistor furnace, which must be operated in a non-oxidizing atmosphere. Ordinarily, hydrogen is used in such a furnace to prevent oxidation of the winding. Hydrogen, however, decarburizes steel at temperatures above about 1292 degrees Fahr. (700 degrees Cent.) Methane, on the other hand, is commonly used as a carburizing gas. By using a controlled mixture of hydrogen and methane, the latter introduced as natural gas, it seemed probable that an atmosphere could be produced which would be exactly neutral at a given temperature for a steel of given carbon content. At the same time the hydrogen would function to protect the furnace winding from oxidation.

THE SYSTEM $\text{CH}_4\text{—H}_2\text{—C}$

Methane, while relatively stable at ordinary temperatures, decomposes into hydrogen and carbon as the temperature rises. The reaction is represented by the equation

²E. D. Campbell, Wm. L. Fink and John F. Ross. The Iron-Iron-Carbide Equilibrium in Dry Hydrogen at 950 Degrees Cent.—*Journal, Iron and Steel Institute*, 1923, No. II.



The higher the temperature, the more complete the decomposition. That is to say, the concentration of CH_4 in equilibrium with H_2 and C becomes smaller as the temperature rises.

In the third column of Table I are listed the volume percentages of CH_4 in equilibrium with C and H_2 at temperatures from 1292 to 2552 degrees Fahr. (700 to 1400 degrees Cent.) These

Table I
Percentage by Volume of CH_4 in Equilibrium with H_2 and C in the
System $CH_4 = C + 2 H_2$

Temp. °C.	Temp. °F.	Per Cent by Volume CH_4	Per Cent by Volume Natural Gas (80% CH_4)
1400	2552	0.08	0.10
1350	2462	0.112	0.14
1300	2372	0.145	0.18
1250	2282	0.185	0.23
1200	2192	0.255	0.32
1150	2102	0.352	0.44
1100	2012	0.485	0.60
1050	1922	0.70	0.87
1000	1832	1.02	1.30
950	1742	1.53	1.90
900	1652	2.30	2.90
850	1562	3.45	4.30
800	1472	5.50	6.90
750	1382	10.0	12.5
700	1292	15.0	18.8

values were obtained from the free energy equation given by Pring and Fairlie³.

The natural gas used as the source of methane in the present work had a composition which varies between the limits given in the following analysis:

CH_4	77	to	82 per cent
C_2H_6	12	to	17 per cent

Throughout this investigation the natural gas was considered to have a methane equivalent of 80 per cent. In the fourth column of Table I are listed the volume percentages of natural gas in equilibrium with hydrogen and carbon at the various temperatures.

DESCRIPTION OF APPARATUS

The diagram in Fig. 1 represents the apparatus used in meas-

³Pring and Fairlie, *Journal of the Chemical Society*, 1912, p. 101-91.

uring, mixing and purifying the hydrogen and natural gas before introducing into the furnace in which the steel was heated. By the use of three carefully calibrated flow gages covering a range between 0.02 and 5.0 cubic feet per hour it was possible to maintain in the atmosphere concentrations of natural gas varying from 0.05 to 25.0 per cent. After mixing, the gases were passed for removal

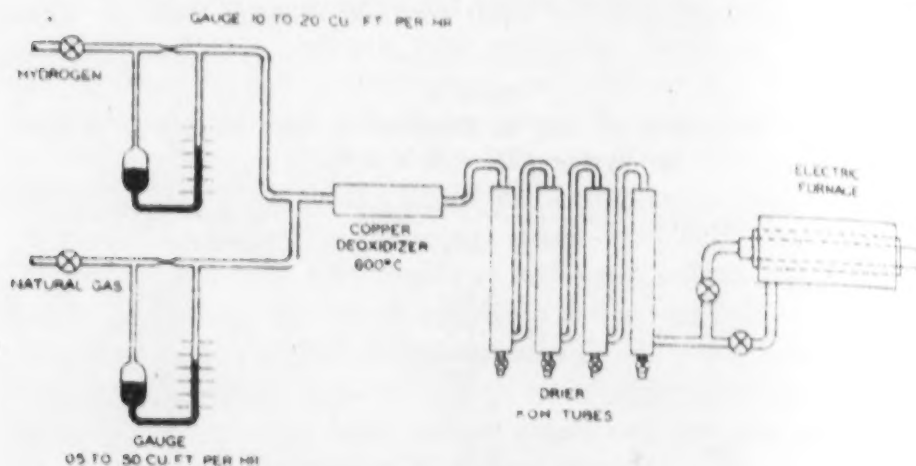


Fig. 1.—Photograph of Gas Mixing and Purifying Train.

of oxygen through an iron tube packed with short pieces of fine copper wire heated electrically to about 1112 degrees Fahr. (600 degrees Cent.) Following the deoxidizer was a drying unit of four 3 inch pipes, 30 inches long, filled with caustic potash and connected in series. An analysis of the gas after this purification with a flow of 20 cubic feet per hour shows a water vapor content below 0.0008 per cent by volume.

The furnace is shown in some detail in Fig. 2. Essentially it consists of an alundum tube $2\frac{1}{2} \times 24$ inches wound with tungsten wire and packed in floated silica contained in a gas tight cast iron box. One or both ends of the alundum tube may extend slightly beyond the wall of the box through an asbestos-packed ring fitting.

In ordinary operation the hydrogen is introduced into the furnace case and by diffusion reaches the interior of the wound tube. This procedure was not satisfactory with mixtures of hydrogen and natural gas. Considerable variations in composition of the furnace atmosphere from time to time were indicated from a fixed composition entering the furnace box. Moreover, as will be mentioned later, the quantities of natural gas required for a neutral

atmosphere were found to be much larger than had been anticipated. It appeared that the gas was being impoverished in carbon before reaching the interior of the tube. This was proved to be the case by leading some of the gas mixture through a $\frac{1}{2}$ -inch iron pipe extending into the furnace which was heated to about 1832 degrees Fahr. (1000 degrees Cent.) After heating for 30 minutes the interior of the small pipe was carburized to a hypereutectoid composition and the exterior appeared to be carbon free.

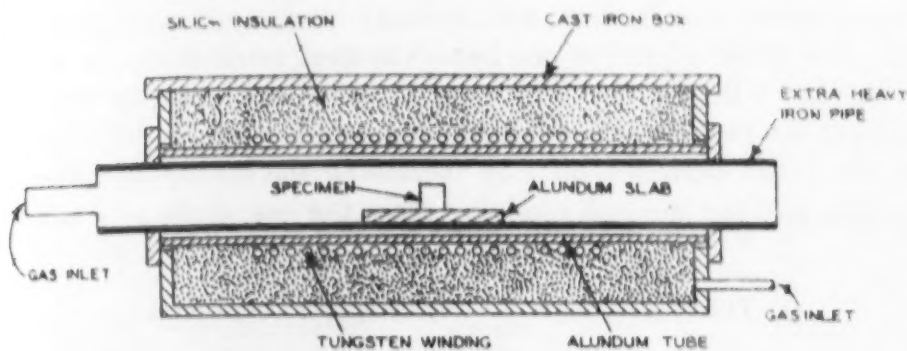


Fig. 2—Photograph of Electric Furnace Used in Heating Steels.

To insure a furnace atmosphere of more nearly constant composition a double extra heavy iron pipe was slipped within the alumina furnace tube. The greater part of the gas was passed into the rear end of this pipe and burned at the open end. Some gas, however, passed into the furnace box to protect the tungsten winding from oxidation. By this arrangement it was possible to maintain an atmosphere of constant composition within fairly close limits at temperatures up to 2012 degrees Fahr. (1100 degrees Cent.) As the temperature was raised above 2012 degrees Fahr. (1100 degrees Cent.) the furnace atmosphere appeared to suffer an increasing loss of carbon. This effect was probably due to the increasingly rapid diffusion of carbon through the iron wall of the pipe to the hydrogen-rich atmosphere outside. By surrounding the pipe with the same gas mixture as that passing into it this difficulty might be to a large extent eliminated. At 2192 and 2372 degrees Fahr. (1200 and 1300 degrees Cent.) a few pieces of steel were heated in a silica tube inserted from the front of the furnace into the iron pipe and supplied with a flow of the same gas mixture which fed the furnace box and pipe.

The results indicated the true direction of the CH_4 — H_2 equilibrium curve in this range of temperature, but due to the extremely small quantities of CH_4 involved no quantitative values could be obtained with the apparatus used.

In using the iron pipe as a heating chamber it is of course necessary that the inner walls of the pipe absorb a certain amount of carbon in order to approach a state of equilibrium with the gas mixture with which they are in contact. To approximate this condition the desired mixture was passed through the tube for two hours after the furnace had reached working temperature. A gas flow of 20 cubic feet per hour was used in all cases. It is possible that a higher rate of flow might have stabilized the composition of the furnace atmosphere at temperatures above 2012 degrees Fahr. (1100 degrees Cent.) by increasing the supply of carbon to compensate for the loss resulting from the use of the iron tube.

DETERMINATION OF NEUTRAL ATMOSPHERES

For an iron-carbon alloy of given carbon content there is at a given temperature one composition of a mixture of CH_4 and H_2 which is neutral to the carbon content of the alloy. The foregoing assumption was the basis for the procedure followed in this investigation.

The method consisted in heating for two hours a steel of known carbon content at a fixed temperature and in a controlled atmosphere of natural gas and hydrogen. The specimens used were round pieces of $\frac{1}{2}$ inch in diameter and $\frac{3}{4}$ inch in length. After removal from the heating chamber they were in most cases transferred to an electric muffle at about 1292 degrees Fahr. (700 degrees Cent.) and allowed to cool with the muffle. The piece was then sectioned through the center, polished, etched and observed under the microscope for change in carbon content near the surface. If the first heating resulted in carburization a second specimen was heated under the same conditions except that the percentage of CH_4 in the gas mixture was lowered. In this manner it was possible to bracket in a few trials the composition of neutral atmosphere. The final value was obtained by heating the specimen for four hours in the atmosphere indicated by the previous trials.

The neutral atmospheres between 1472 and 2552 degrees Fahr.

(800 and 1400 degrees Cent.) were determined for four steels of the following composition.

Carbon	0.18 — 0.30 — 0.59 — 0.92
Manganese	0.50 to 0.80
Silicon	0.10 to 0.20

In Table II are listed the observed percentages of natural gas in the neutral atmospheres for three of these steels at a series of

Table II
Per Cent of Natural Gas (80 Per Cent CH_4) in Mixture of Natural Gas and Hydrogen to Form Neutral Atmosphere for Steels

Temperature, Degrees Cent.	Temperature, Degrees Fahr.	0.18% C Steel In Iron Pipe		In Silica Tube	0.59% C Steel In Iron Pipe		0.95% C Steel In Iron Pipe	
		Calculated	Observed		Calculated	Observed	Calculated	Observed
1400	2552	0.0027	1.9	.....	.....	.....	.....	.....
1300	2372	0.0048	0.40	> 0.05	.....	.....	.....	.....
1200	2192	0.0085	0.20	> 0.05	0.028	0.70	.....	.....
1100	2012	0.067	0.08	0.08	0.22	0.25	0.35	0.40
1000	1832	0.167	0.15	0.15	0.55	0.50	0.88	0.90
900	1652	0.430	0.40	0.40	1.43	1.50	2.30	2.50
800	1472	1.12	1.20	1.20	3.70	3.90	5.90	6.00

temperatures. The values in the columns headed "calculated" were arrived at from the following considerations.

An atmosphere of CH_4 and H_2 of equilibrium composition at a given temperature must be in equilibrium with solid carbon and also with a saturated solution of carbon in iron. In the case under discussion the saturated solutions of carbon in iron are solid below 2084 degrees Fahr. (1140 degrees Cent.) If, at a given temperature, there is in the atmosphere an excess of hydrogen over that concentration required for equilibrium in the system, then the hydrogen will react with the carbon in the austenite to form additional CH_4 resulting in decarburization of the steel. If, on the other hand, CH_4 is present in excess it will tend to decompose into H_2 and solid carbon. Should this precipitation of solid carbon take place on the surface of a steel unsaturated in carbon at this particular temperature, the carbon will dissolve in the iron up to the saturation value and with sufficient time for diffusion result in a steel of uniform carbon concentration throughout.

The following values for carbon content of saturated austenite

taken from the iron carbon diagram of Howe⁴ have been used in the computation.

Temperature in Degrees		Per Cent Carbon in Saturated Austenite
Cent.	Fahr.	
1140	2084	1.7
1100	2012	1.6
1000	1832	1.4
900	1652	1.2
800	1472	1.0

From Table I the system $\text{CH}_4\text{—H}_2\text{—C}$ in equilibrium at 1832 degrees Fahr. (1000 degrees Cent.) contains 1.02 per cent of CH_4 . This is taken to be equivalent to 1.3 per cent natural gas. At 1832 degrees Fahr. (1000 degrees Cent.) iron will hold in solid solution about 1.4 per cent of carbon. The vapor pressure of the carbon in this saturated austenite should then be equal to the vapor pressure of the carbon in the atmosphere $\text{CH}_4\text{—H}_2\text{—C}$ containing 1.3 per cent natural gas.

It is assumed that at a given temperature the vapor pressure of the carbon in an austenite containing but one half the carbon necessary for saturation is equal to the vapor pressure of carbon in the $\text{CH}_4\text{—H}_2\text{—C}$ atmosphere in which the concentration of CH_4 is one half that required for equilibrium in the system.

Thus for an austenite containing 0.95 per cent carbon the CH_4 content of a neutral atmosphere at 1832 degrees Fahr. (1000 degrees Cent.) is calculated:

$$\frac{\% \text{ C in 0.95\% C Austenite}}{\% \text{ C in saturated Austenite}} \times \frac{\% \text{ CH}_4 \text{ in atmosphere for saturation}}{\% \text{ CH}_4 \text{ in atmosphere for equilibrium with 0.95\% C Austenite, or}} =$$

$$\frac{0.95}{1.40} \times 1.3 \text{ (natural gas equivalent)} = 0.88\%$$

In Table II the observed value for the percentage of natural gas required by the conditions of the foregoing example is given as 0.90. This agreement is as close as might be expected under the conditions of the experiment if the assumption were correct.

Figs. 3 to 8 inclusive illustrate the changes observed near the surfaces of specimens of two steels heated in decarburizing, neutral and carburizing atmospheres respectively.

The curve A in Fig. 9 is drawn from observed concentrations of natural gas in an atmosphere neutral to a steel of 0.18 per cent carbon content.

⁴The Metallography of Steel and Cast Iron—Henry M. Howe, p. 130.

1927

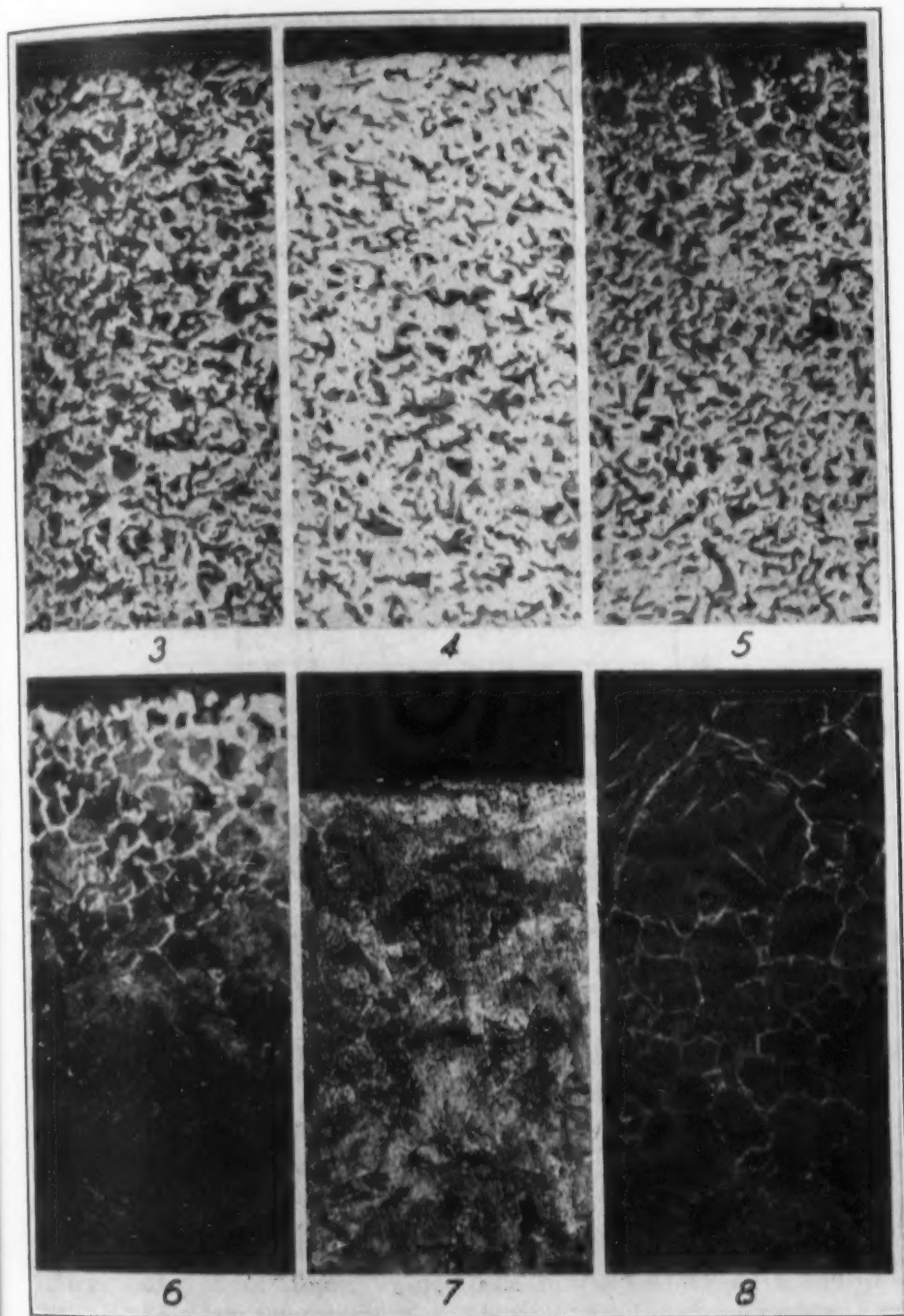


Fig. 3—Photomicrograph of 0.3 Per Cent Carbon Steel Heated 2 Hours at 1652 Degrees Fahr. in Neutral Atmosphere of H_2 + 0.7 Per Cent Natural Gas. No Noticeable Change in Carbon Content. 50X. Fig. 4—0.3 Per Cent Carbon Steel Heated 2 Hours at 1652 Degrees Fahr. in H_2 + 0.5 Per Cent Natural Gas. Decarburized. 50X. Fig. 5—0.3 Per Cent Carbon Steel Heated 2 Hours at 1652 Degrees Fahr. in H_2 + 0.9 Per Cent Natural Gas. Carburized. 50X. Fig. 6—0.95 Per Cent Carbon Steel Heated 2 Hours at 2012 Degrees Fahr. in H_2 + 0.2 Per Cent Natural Gas. Decarburized. 50X. Fig. 7—0.95 Per Cent Carbon Steel Heated 2 Hours at 2012 Degrees Fahr. in H_2 + 0.4 Per Cent Natural Gas. Unchanged in Carbon Content. 50X. Fig. 8—0.95 Per Cent Carbon Steel Heated 2 Hours at 2012 Degrees Fahr. in H_2 + 1.0 Per Cent Natural Gas. Carburized. 50X.

Reference to the equilibrium diagram of the iron-carbon system will show that at temperatures above 2084 degrees Fahr. (1140 degrees Cent.) iron in an atmosphere saturated with carbon will

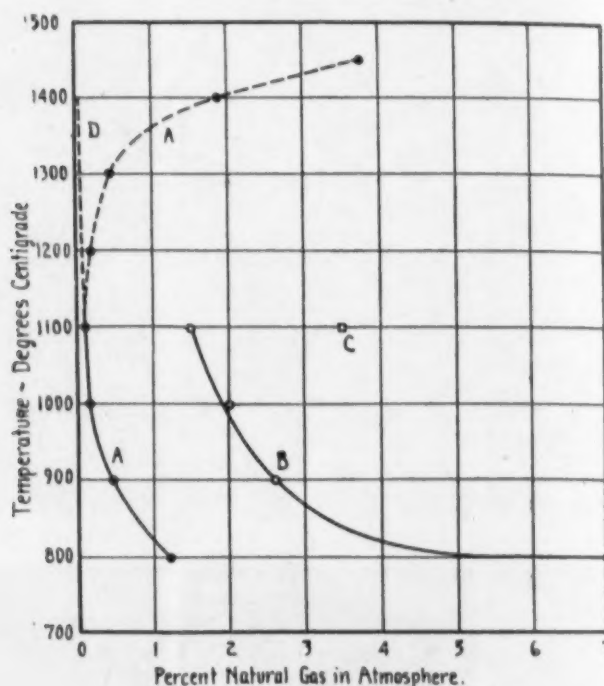


Fig. 9—Curves Showing Observed Percentages of Natural Gas (50 Per Cent CH_4) in Atmosphere of Natural Gas and Hydrogen in Equilibrium with Steel of 0.18 Per Cent Carbon Content at Atmospheric Pressure.

- A—Gas Mixture Deoxidized and Dried
- B—Gas Mixture Containing 0.6% by Volume H_2O
- C—Gas Mixture Containing 3.3% by Volume H_2O
- D—Indicated Concentration in Atmosphere Under Ideal Conditions of Heating.

eventually be transformed complete to Fe_3C (cementite) assuming that Fe_3C is the stable phase.

At temperatures between 2084 and 2786 degrees Fahr. (1140 and 1530 degrees Cent.) the liquid phase exists. In a steel of given carbon content at a constant temperature within its freezing range the solid solution of lower carbon content must be in equilibrium with the liquid solution of much higher carbon content. Throughout this temperature range the conditions of equilibrium between the atmosphere and the steel become somewhat involved and their consideration is not included in the present discussion.

The true trend of the CH_4 concentration curve is indicated

1927

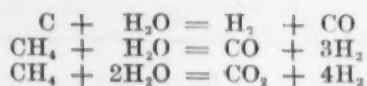
by results obtained from heating steels in a silica tube placed within the iron pipe ordinarily used as the heating chamber. By this arrangement it was possible to maintain at 2372 degrees Fahr. (1300 degrees Cent.) the CH_4 concentration as originally mixed. After heating for more than two hours, however, the atmosphere within the silica tube began to lose carbon rapidly due presumably to the increasing porosity of the silica.

In Fig. 10 is shown the surface of a 0.3 per cent carbon steel heated in a silica tube at 2372 degrees Fahr. (1300 degrees Cent.) in an atmosphere of hydrogen containing 0.2 per cent natural gas. After heating for 30 minutes the outer portion of the steel has reached the eutectic composition and fused. This has occurred in the presence of 0.2 per cent natural gas while at 2012 degrees Fahr. (1100 degrees Cent.) a 0.95 per cent carbon steel requires 0.4 per cent natural gas in a neutral atmosphere.

EFFECT OF WATER VAPOR IN THE GAS

The influence of moisture in the hydrogen on the efficiency of decarburization has been investigated by Campbell, Ross and Fink⁵. In their summary they state that "Moist hydrogen is not only more efficient than dry hydrogen in decarburization at 1742 degrees Fahr. (950 degrees Cent.), but is essential to complete decarburization."

To determine the effect of water vapor on the carburizing action of this gas mixture the mixed gas after the usual deoxidizing and drying was saturated with water vapor at 32 degrees Fahr. (0 degrees Cent.) In this condition the gas contained 0.6 per cent by volume of water vapor. As shown in curve B, Fig. 9, the presence of this quantity of water vapor makes it necessary to add several times the quantity of CH_4 required when the gas is dry. This is presumably due to the decomposition of the CH_4 according to the following reactions.



These reactions tend to remove the CH_4 from the system and

⁵E. D. Campbell, Wm. L. Fink and John F. Ross—The Relative Efficiency of Dry and of Moist Hydrogen on the Decarburization of Steel at 950 Degrees Cent., and the Effect on Hydrogen of the Phosphorus Content, *Journal, Iron and Steel Institute*, 1923, No. II.

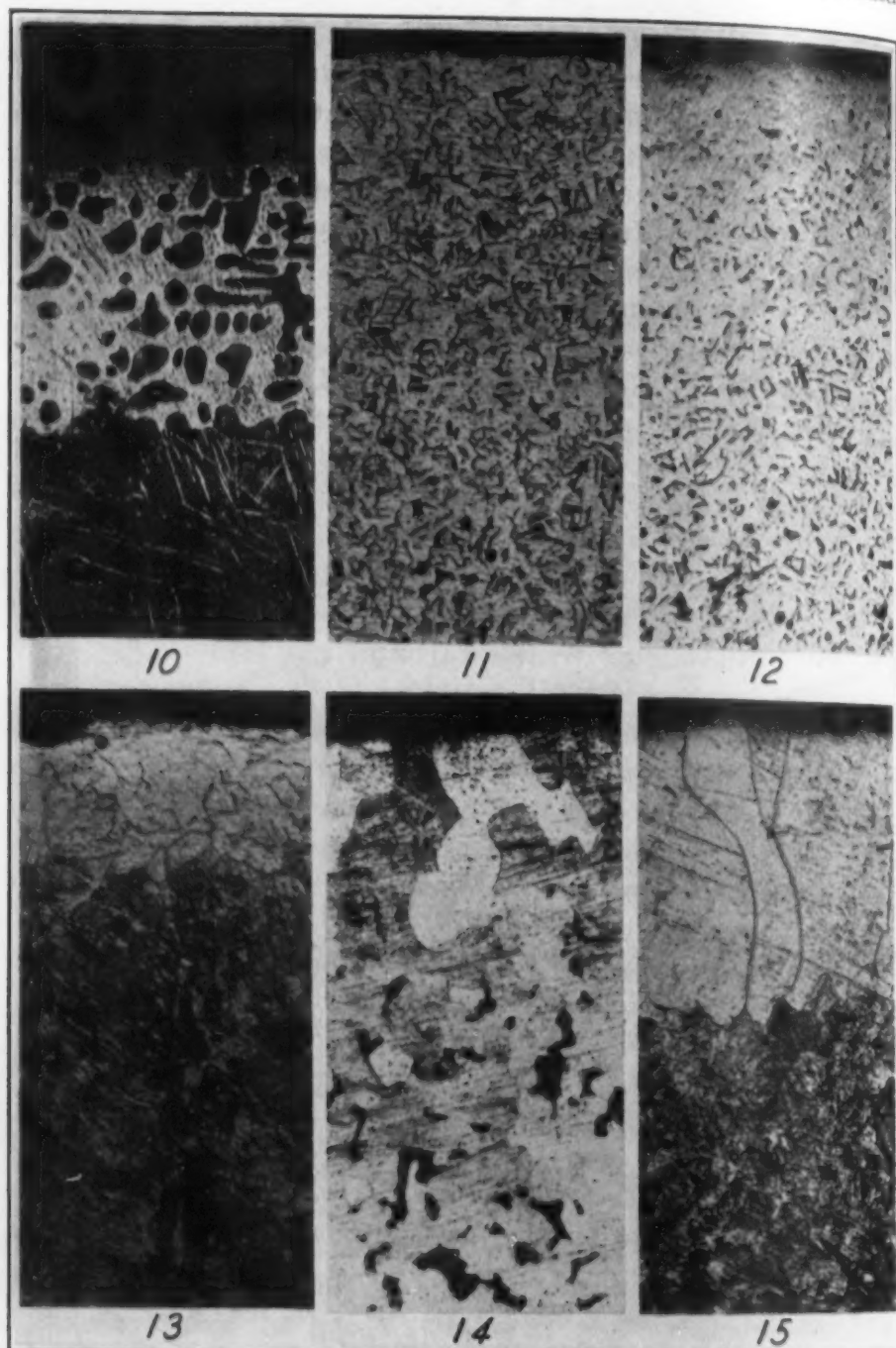


Fig. 10—Photomicrographs of 0.3 Per Cent Carbon Steel Heated in Silica Tube at 2282 Degrees Fahr. 90 Minutes in H_2 + 0.2 Per Cent Natural Gas. 100X. Fig. 11—0.2 Per Cent Carbon Steel Heated 2 Hours at 2012 Degrees Fahr. in Hydrogen, Deoxidized and Dried. 50X. Fig. 12—0.2 Per Cent Carbon Steel Heated 2 Hours at 2012 Degrees Fahr. in Hydrogen Containing 3.3 Per Cent of Water Vapor. 50X. Fig. 13—0.3 Per Cent Carbon Steel Heated 2 Hours at 1742 Degrees Fahr. in Moist Hydrogen Quenched. 100X. Fig. 14—0.3 Per Cent Carbon Steel Heated 2 Hours at 1742 Degrees Fahr. in Moist Hydrogen—Slowly Cooled. 100X. Fig. 15—0.3 Per Cent Carbon Steel Heated 2 Hours in 1472 Degrees Fahr. in Moist Hydrogen, Quenched. 100X.

while CO under certain conditions has a carburizing action on iron, the net result of its formation in this case is to radically lessen the carburizing power of the mixture. Figs. 11 and 12 contrast the decarburizing speeds of dry and wet hydrogen at 2012 degrees Fahr. (1100 degrees Cent.)

Steel heated in hydrogen dried and deoxidized as described above will be decarburized at a moderate rate, with the formation of CH_4 ;



While CH_4 becomes more stable as the temperature is lowered the net loss of carbon by the steel is influenced by the slower diffusion of carbon through the iron at lower temperatures. It has been observed that decarburization by hydrogen takes place most rapidly at temperatures between 1652 and 1832 degrees Fahr. (900 and 1000 degrees Cent.)

During decarburization of a steel at 2012 degrees Fahr. (1100 degrees Cent.) by hydrogen the carbon concentration appears to decrease gradually toward the surface. As the hydrogen removes the carbon from the surface the loss is in part made good by rapid diffusion of carbon from within. Note that in Fig. 12 the patches of pearlite extend well out to the edge of the steel. At lower temperatures the decreased diffusion rate results in a much steeper gradient in carbon concentration. (Figs. 14 and 16.) This effect is especially pronounced when the action has occurred at a temperature below 1652 degrees Fahr. (900 degrees Cent.)

By quenching the steel after partial decarburization at 1472 degrees Fahr. (800 degrees Cent.) there is a sharp line of demarcation dividing the martensitic central portion and the shell of coarse grained alpha iron. (Fig. 15.) It is apparent that at the moment of quenching the carbon was diffusing from the austenitic central region to the surface but at a limited rate, because of the low solubility of carbon in the outer shell of alpha iron. During decarburization at 1742 degrees Fahr. (950 degrees Cent.), however, the carbon concentration is maintained at an appreciable value well toward the surface of the steel. (Fig. 13.)

CARBURIZING ARMCO IRON

The effects of time, temperature and CH_4 concentration on

Tube at 2282
-0.2 Per Cent
Dried. 50X.
in Hydrogen
steel Heated 2
-0.3 Per Cent
cooled. 100X.
ist Hydrogen.

carburizing rate were studied by heating specimens of Armco iron under various conditions. In Table III are listed the depths of penetration observed.

The blocks were heated in the iron pipe and the CH_4 con-

Table III
Depth of Penetration of Carbon in Iron Heated in Atmosphere of
Hydrogen and Natural Gas (80 Per Cent CH_4)

Temp. Deg. C.	Concentration of CH_4	Time Hrs.	Depth of Penetration Mms.
1100	Saturation	One	0.5-0.6
		Three	1.6-1.8
	2x Saturation	One	1.0
		Three	1.6-1.8
	4x Saturation	One	1.0
		Three	1.6-1.8
950	Saturation	One	0.4-0.5
		Three	1.2-1.4
850	Saturation	One	0.25-0.30
		Three	0.6-0.7
	2x Saturation	One	0.25-0.30
		Three	0.6-0.7
760	Saturation	One	0.04-0.05
		Three	0.08-0.10

centrations used were multiples of the saturation values at the working temperatures given in Table I.

Here again the rate of diffusion of carbon is the important factor determining the total depth of penetration. Note that at 2012 degrees Fahr. (1100 degrees Cent.) the total depth of penetration after 1 hour is noticeably increased by the doubling of the CH_4 concentration. A second increase in concentration results in no further increase in penetration depth. At this temperature, and with a CH_4 saturation content in the gas the depth of penetration is nearly proportional to the time.

In general an increase in CH_4 concentration results in a steeper gradient in the carburized zone. The characteristics of some of the cases obtained are illustrated in Figs. 18 to 24 inclusive.

In Figs. 25, 26 and 27 are shown three stages in the process of

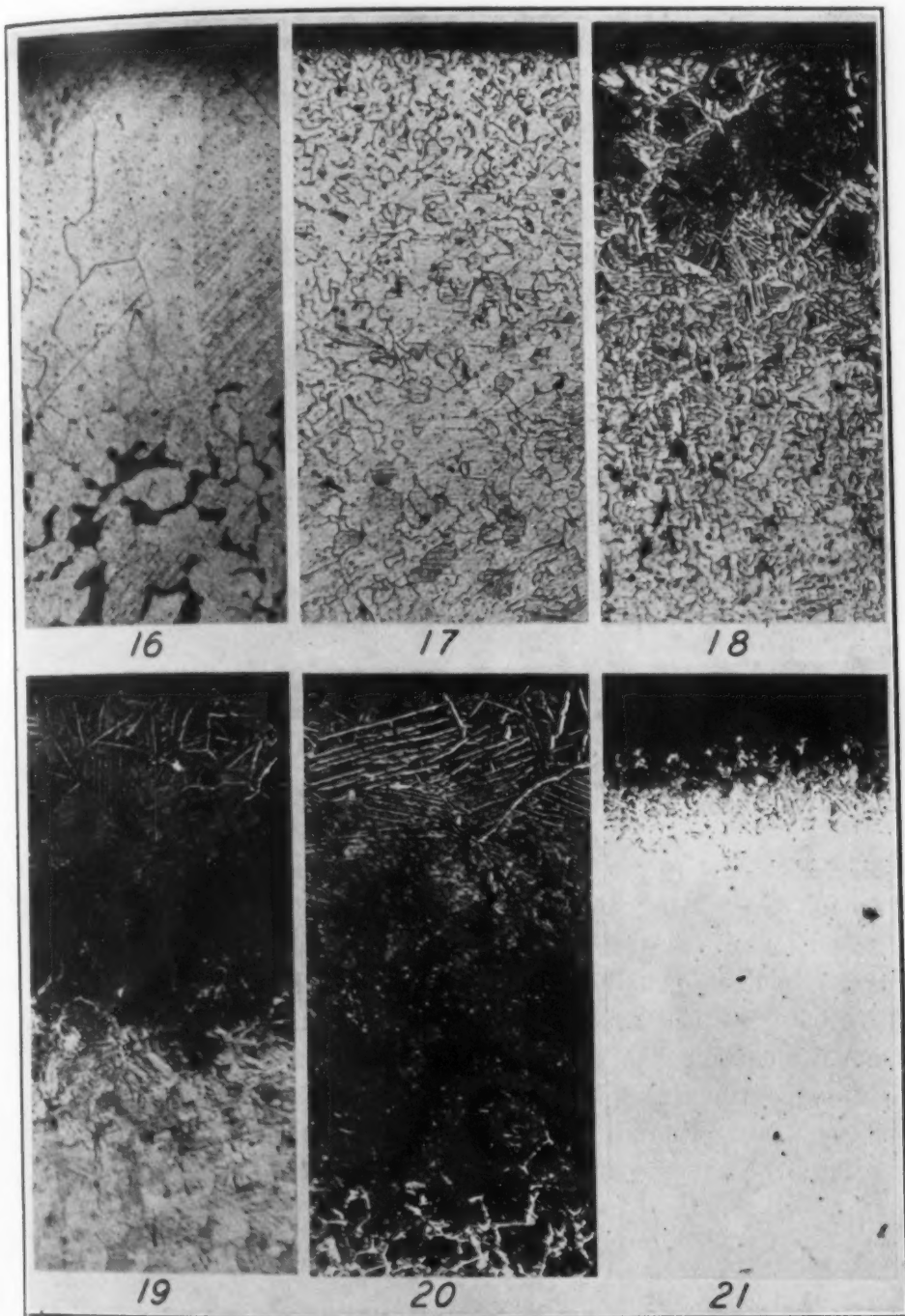


Fig. 16—Photomicrograph of 0.3 Per Cent Carbon Steel Heated 2 Hours at 1472 Degrees Fahr. in Moist Hydrogen, Slowly Cooled. 100X. Fig. 17—Armco Iron Heated 1 Hour at 2012 Degrees in 0.6 Per Cent Natural Gas in H_2 . 50X. Fig. 18—Armco Iron Heated 3 Hours at 2012 Degrees Fahr. in 0.6 Per Cent Natural Gas. 50X. Fig. 19—Armco Iron Heated 1 Hour at 2012 Degrees Fahr. in 2.4 Per Cent Natural Gas. 50X. Fig. 20—Armco Iron Heated 3 Hours at 2012 Degrees Fahr. in 2.4 Per Cent Natural Gas. 50X. Fig. 21—Armco Iron Heated 1 Hour at 1562 Degrees Fahr. in 8.6 Per Cent Natural Gas.

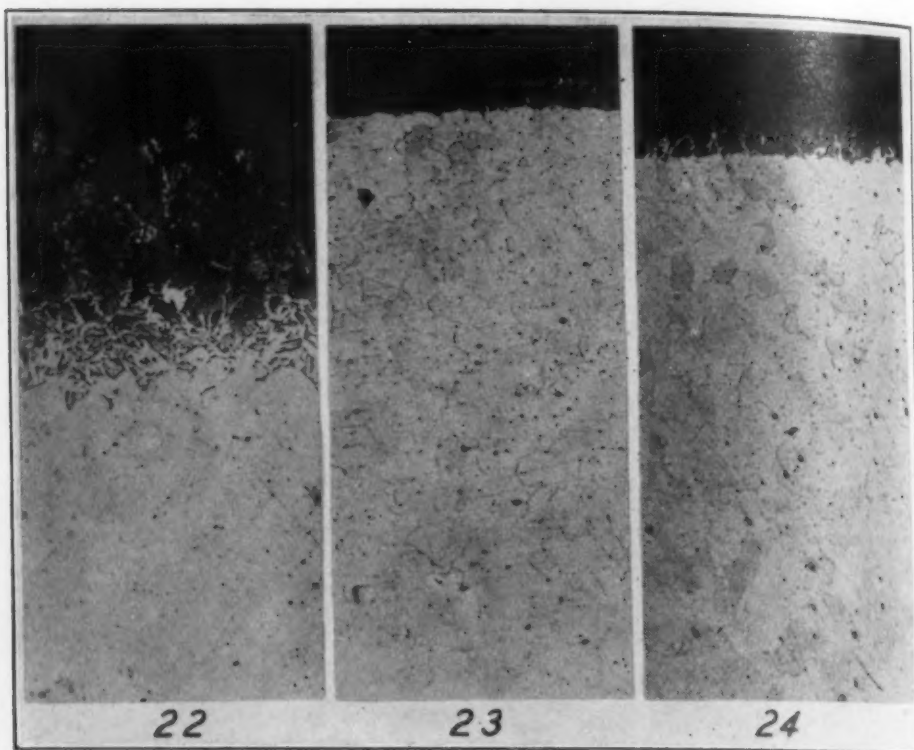


Fig. 22—Photomicrograph of Armco Iron Heated 3 Hours at 1562 Degrees Fahr. in 8.6 Per Cent Natural Gas. 50X. Fig. 23—Armco Iron Heated 1 Hour at 1400 Degrees Fahr. in 12.0 Per Cent Natural Gas. 50X. Fig. 24—Armco Iron Heated 2 Hours at 1400 Degrees Fahr. in 12.0 Per Cent Natural Gas. 50X.

uniformly carburizing to a desired carbon content a section of Armco iron 0.250 inch in thickness. The first treatment at 2012 degrees Fahr. (1100 degrees Cent.) with a high CH_4 concentration results in deep penetration but an excess of carbon near the surface. During the subsequent heating the carbon diffuses inward from the carbon rich area and the outer portions approach equilibrium with the atmosphere which is of the concentration for desired final carbon content in the steel. The photomicrographs represent one half the thickness of the carburized blocks.

SUMMARY

Concentrations of methane and hydrogen are found to follow closely the theoretical values in atmospheres neutral to austenite of given carbon content at temperatures between 1400 and 2012 degrees Fahr. (760 and 1100 degrees Cent.) It is apparent, however, that for heating conditions which do not approximate those

F
at 201
Subse
(Atmo
Hours

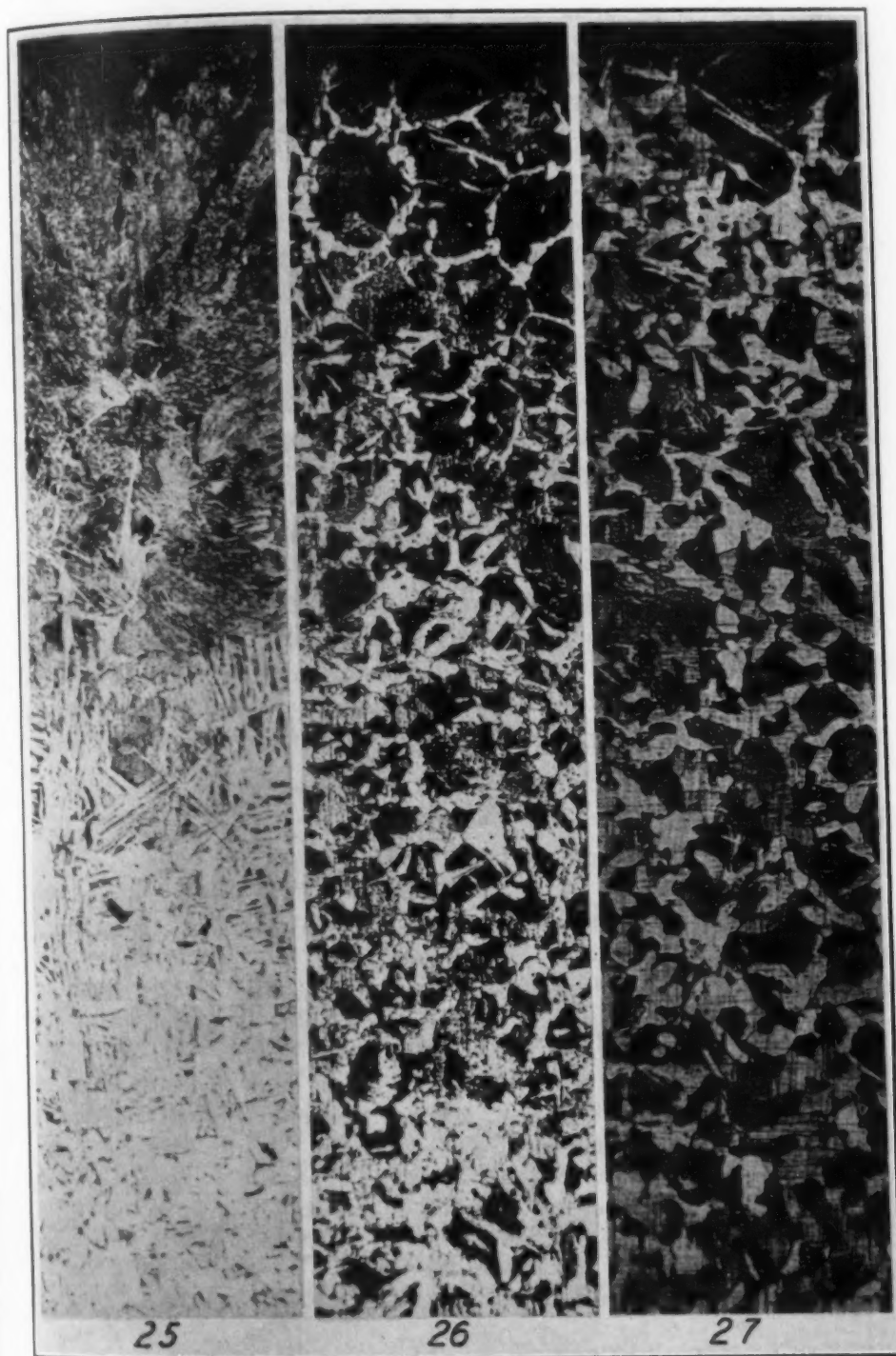


Fig. 25—Iron Slab 0.250 Inches Thick—Section Extends from Surface to Center. Heated at 2012 Degrees Fahr. for 6 Hours in H_2 + 1.5 Per Cent Natural Gas. 50X. Fig. 26—Same Subsequently Heated at 2012 Degrees Fahr. for 4 Hours in H_2 + 0.2 Per Cent Natural Gas (Atmosphere Neutral to 0.5 Per Cent Carbon Steel). 50X. Fig. 27—Same Heated for 8 Hours at 2012 Degrees Fahr. in H_2 + 0.2 Per Cent Natural Gas. 50X.

described in the foregoing pages the gas concentrations for neutral atmospheres must be determined by trial.

The presence of moisture disturbs the equilibrium of the CH_4 - H_2 -C system very markedly. A moist gas mixture has less carburizing effect than a dry atmosphere of the same methane content (concentrations measured at room temperatures). In carburizing iron by the hydrogen-methane atmosphere the depth of carbon penetration is largely determined by the diffusion rate of the carbon. Increase in concentration of methane results primarily in higher carbon content of iron near the surface.

By proper concentrations of methane and hydrogen it is possible to uniformly carburize to predetermined carbon content iron blocks $\frac{1}{4}$ inch in thickness.

ACKNOWLEDGEMENTS

A. B. Gladding of the Cleveland Wire Works staff of the General Electric Company contributed valuable aid throughout the course of this investigation. The flow gages used were of his design and construction, and his help in computing the equilibrium concentrations of the gases was especially welcome.

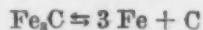
For the steels used in this work the writer is indebted to H. H. Smith of the Bourne-Fuller Company, Cleveland.

DISCUSSION

Written Discussion: By H. A. Schwartz, National Malleable and Steel Castings Co., Cleveland.

Mr. Sykes' paper, "Carburizing Iron by Mixtures of Hydrogen and Methane," suggests to the writer certain considerations which, though perhaps but indirectly connected with that research, may be of some interest in its consideration. An attempt has been made in these comments to discuss the thermo-dynamic probabilities of Mr. Sykes' problem rather than to offer comment upon the results secured.

At such temperatures as here considered cementite is distinctly metastable, a fact which is probably generally accepted and in support of which much evidence is available in the literature. Cementite breaks up, though perhaps not directly into its constituent elements and the graphitizing reaction is generally written



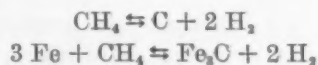
which must not be understood to preclude intermediate reactions, the formation of solid solutions and so on.

Now the metastability of cementite seems to imply, among other things,

that the vapor pressure of carbon from Fe_3C is under given conditions, greater than that from iron. If austenite be interpreted, as it must be in the reference to Howe, as the solid solution of the system $Fe-Fe_3C$, then the carbon vapor pressure of saturated austenite at a given temperature is that of cementite and not necessarily that of carbon whose presence, as the element, is not recognized by the diagram.

Assuming the metastability of cementite this vapor pressure must then be not equal to but greater than the vapor pressure of carbon. Any solid solution having a carbon vapor pressure equal to that of carbon is saturated with respect to carbon and *ipso facto* not saturated with respect to cementite in which carbon must be more soluble than in the free form if the carbide is metastable. The differences in solubility and vapor pressure may be small but must be in the direction indicated or else energy would not be liberated by the decomposition of cementite and that compound would not be metastable.

In this connection we may refer to Schenck¹ who in table 5 on page 672 gives data due to Krägeloh and Eisenstecken as to the equilibria in the reactions



showing definitely higher contents of H in the former equilibria than in the latter in the temperature range from 310 to 720 degrees Cent. It would seem that by use of the greatly hypereutectoid steels the table might be extended to higher temperatures.

Mr. Sykes' calculations from Pring and Fairlie are all at higher temperatures but apparently these workers' data lead to lower CH_4 concentrations in the system CH_4-C-H than Krägeloh and Eisenstecken's.

In a two-phase system consisting of saturated solid solution and solute we may be reasonably sure perhaps that the solution is saturated with respect to the solute phase present in excess. In unsaturated solutions however, such investigations as Mr. Sykes' furnish an excellent method of determining something of the effect of concentration on carbon vapor pressure and if in the present case we find an identity of pressure with that of carbon or cementite at the same temperatures we may infer saturation with respect to these solutes. The fact that Mr. Sykes finds that a solid solution of concentration known to be saturated with respect to cementite to have the same carbon vapor pressure, as carbon, equivalent to saying that it has the same composition of gas phase as would be in equilibrium with carbon seems to the writer irreconcilable with the metastability of Fe_3C .

The causes may be many:—the A_{cm} line of the pure iron carbon system is probably not known with the highest precision, the effect of manganese on its location is not at all well known and may not be negligible, the effect of ethane which may enter into the reaction also may not be negligible as it would be were it an inert gas which merely lowered the pressure by 15 per cent or so or equilibria may be approached too slowly to permit of microscopic detection in the times used.

¹"Eisen, Kohlenstoff und Sauerstoff in ihren wechselseitigen Beziehungen", *Stahl und Eisen*, Vol. 46, page 665, 1926.

All these possibilities are not presented from the viewpoint of criticizing Mr. Sykes' methods, for his purpose did not at all require him to exclude these variables. The intention here is merely to point out the thermodynamic improbability of the precise quantitative accuracy of an inference lest ultimately misunderstanding may result.

If the solute in the iron-carbon system is always the same, which the writer doubts,² i. e. if Boydenite and Austenite differ only in carbon concentration then we may draw certain conclusions. The vapor pressure of C from its solution in gamma iron will be, at a given temperature, some function of carbon concentration as for example, a simple linear function as assumed by Sykes. Its locus possibly passes through the origin and must pass through the vapor pressure of carbon at the concentration marking the solubility of carbon from the free state and through the vapor pressure of carbon from Fe_3C at the concentration corresponding to the solubility of C from Fe_3C .

Although the existence of a locus of mathematically simple form passing through these points would raise a presumption of an identity of solute, it does not necessarily demonstrate its existence. For postulating a difference of solute we should obtain two branches, one passing through the Fe_3C vapor pressure, the other through the carbon vapor pressure, the carbon vapor pressure of the former always higher than of the latter. The experimental realization of equilibrium would, however, only be possible under conditions rendering a change of solute impossible. These conditions might be either the total elimination of the metastable solute rendering impossible an exploration of its characteristics or some means of so retarding the formation of the stable solute as to prevent its formation from interfering with the gas reactions.

If a progressive change of kind of solute with concentration can occur then a smooth line joining the carbon vapor pressures of C and Fe_3C at the appropriate concentrations will still be obtained but will not represent true equilibrium in either system. Reference should perhaps, here be made to the work of Takahasi³ who investigated the relation of the CO-CO_2 equilibrium for various concentrations of carbon in austenite. Takahasi's results, however, instead of intersecting a line marking the true Fe_3C equilibrium came to one representing the Fe_3C equilibrium in the presence of dissolved oxygen which was earlier misinterpreted by both Schenck and Matsubara as the true one.

It appears therefore, that his results are not comparable with those now obtained by Sykes even by appropriate calculation, for the latter's work excludes the contamination which vitiated Takahasi's.

As to the locus of these carbon concentration vapor pressure isothermals they can reach the origin only at temperatures above A_1 for pure iron. Low carbon steels below A_1 are non-homogeneous consisting of alpha iron and a solution of carbon in some form in gamma iron presumably.

The vapor pressure of carbon at any temperature from pure ferrite is probably near zero although it may have a small finite value due to the small

²"Evidences Concerning the Location of the Carbon Atom in Boydenite", TRANSACTIONS, American Society for Steel Treating, Vol. XI, Part 2, page 277, 1927.

³"On Equilibrium Between Austenite and Carbon Oxides", Science Reports of the Tohoku Imperial University, Vol. XV, No. 2, May, 1926.

but finite solubility of carbon in alpha iron. Moreover the solubility of C in delta iron indicates a slight rise of solubility with temperature. If the vapor pressure at or below A_3 of the carbon from gamma iron solution were higher than this, carbon would go from gamma iron solution into alpha iron and carbonize the latter. To the extent therefore that the body centered iron in equilibrium with austenite below A_3 is carbon free a finite vapor pressure for carbon from steel below its A_3 point seems improbable.

Mr. Sykes has, no doubt, not overlooked the fact that in steels at temperatures between the liquidus and solidus the solid and liquid phases in equilibrium with each other are necessarily each in equilibrium with the same gas phase which is in equilibrium with the two phase metal system. It follows as a corollary that the vapor pressure of carbon for a given temperature and concentration is less from liquid than from solid solutions.

Written Discussion: By W. L. Fink, Aluminum Company of America, Cleveland.

Mr. Sykes' laudable work is of considerable interest both on account of its theoretical aspects, and on account of its utility in laboratory work. The quantitative nature of the results is a distinct addition to the previous results obtained by Professor E. D. Campbell.

There are, however, two points brought out by Professor Campbell's work which it might be well to mention. There were indications that methane is not the only hydrocarbon formed in the system $Fe-C-H_2$ -hydrocarbon, but that a small amount of higher homologues is formed at least at 950 degrees Cent. Although the amount is small, and would probably decrease with increasing temperature, it is well to realize its existence.

The second and more important point is the effect of the composition of the steel upon the equilibrium. It was found that chromium, silicon, and manganese each displace the equilibrium very appreciably. The alloying element causes the steel to reach a higher carbon content than does armco iron with a given composition of the gaseous phase. Other alloying elements would be expected to affect the equilibrium constant, or the composition of the neutral atmosphere for a given carbon content in the steel.

It might be of interest to note that this equilibrium was used to prepare all of the specimens used in the work done by Professor Campbell from 1922 until his death.

Written Discussion: By W. J. Merten, Westinghouse Electric and Manufacturing Co., Pittsburgh.

Mr. Sykes' paper is of a great deal of interest, not so much from the standpoint of carburization in atmosphere of $H_2 + CH_4$, but from the standpoint of information regarding reaction of various gas mixtures on iron or steel at temperatures employed for thermal treatment such as annealing and hardening of steels and alloys. Ordinarily, a slight amount of oxidation resulting in a bluing or in a thin lightly clinging oxide, is rarely objectionable, neither is a superficial carburizing effect detrimental during thermal treatments of steel parts. The quantitative ratios of gas mixtures to be passed through furnace chambers to assure non-scaling or practically non-carburizing condition in annealing of sheets, drop forgings, and castings, constitutes valuable

data and data of great importance in heat treating practices conducted in sheet rolling mills, forge shops and steel foundries, and the author is to be highly commended for the contribution of data along a line of activity to which, so far, sufficient attention has not been paid by investigators.

Heating under selective atmospheric conditions assuring definite preservation of surface condition will be practiced to a far greater degree in the near future than we are doing at present, and this kind of data is of immense help to stimulate such development work.

Author's Reply to the Written Discussion

Mr. Schwartz has in his discussion introduced certain theoretical points which are highly pertinent to the subject outlined in the paper. Unfortunately the limitations of the method and apparatus employed are such as to preclude any strictly quantitative determinations.

It was doubtless inconsistent to base the carbon concentration for saturated austenite upon the solid solubility curve of cementite, since there must be a difference between the vapor pressures of pure carbon and carbon in the form of cementite.

Apparently this difference through the temperature range considered in these experiments is so slight as to require extremely precise methods for its detection.

Since receiving Mr. Schwartz's discussion I have heated a 1.58 per cent carbon steel at 900 degrees Cent. for two hours in an atmosphere of hydrogen saturated (approximately) with methane. No change in the amount of excess cementite from the surface inward could be detected.

HEAT TREATMENT OF TWO BALL BEARING STEELS

BY BENGT KJERRMAN

Abstract

This paper gives the results of electrical resistance tests on two ball bearing steels, one of the common type, the other with a higher content of chromium and the addition of molybdenum. By resistance measurements on water quenched test specimens, it is shown that it is possible to determine the quantity of alloying elements which are effective in hardening a given steel. It is shown that the per cent hardening efficiency may be lowered by the addition of too great a quantity of alloying elements. This testing method should then afford a means of determining the cheapest analysis for a steel of definite mechanical properties with definite hardening methods.

THE two steels which were used in this investigation had the following compositions:

Heat	Composition in Per Cent						
	C	Cr	Mo	Mn	Si	P	S
U-887	1.01	1.54	...	0.38	0.354	0.024	0.008
Y-208	1.00	1.77	0.21	0.41	0.282	0.020	0.012

These steels were made in acid open-hearth furnaces and were tested by electric resistance measurements at varying temperatures; by electrical resistance measurements at constant temperature on specimens quenched in water from different temperatures¹ ("hardening curves"), and finally subjected to experimental annealing and hardening tests with subsequent hardness determinations and microscopic examination.

With steel U-887 nine different tests were made. The results are shown in Tables I and II, and graphically shown in Figs. 1 and 2.

¹TRANSACTIONS, American Society for Steel Treating, 1926, pp. 430-451.

A paper presented before the ninth annual convention of the society held in Detroit, September 19 to 23, 1927. The author, Bengt Kjerrman, a member of the society, is metallurgical engineer, Aktiebolaget Svenska Kullagerfabriken, Gothenberg, Sweden. Manuscript received May 27, 1927.

Table I
Electrical Resistance Measurements at Varying Temperatures

Test No.	Original dimension	Specimen No.	Previous Treatment	Ac ₁ interval degrees Fahr.	Ar ₁ interval degrees Fahr.
1	.197-inch square	1	Untreated after forging. Annealed at 1256 degrees Fahr.	1360-1386	....
2	.197-inch square	1	Comparatively quick cooling in furnace from 1418 degrees Fahr.	1362-1386	....
3	.197-inch square	1	Comparatively quick cooling in furnace from 1461 degrees Fahr.	1360-1387	....
4	.197-inch square	2	Untreated after forging. Annealed at 1292 degrees Fahr.	1362-1387	1355-1328
5	.197-inch square	2	Soft annealed at 1436 degrees Fahr.	1364-1396	....
6	.197-inch square	3	Untreated after forging. Annealed at 1112 degrees Fahr.	1360-1387	....
7	.197-inch square	4	Soft annealed at 1436 degrees Fahr.	1362-1389	....
8	3.54 inches round	5	Untreated after rolling.	1362-1387	....
9	3.54 inches round	6	Untreated after rolling.	1360-1387	....

Specimen 1 (tests 1-3) is from one forging; specimens 2, 3, and 4 from another forging (tests 4-7). The first forging operation was carried out at much higher temperature than the second one, as is seen from Table II. The specific resistance at room temperature (26.2) is about the same as that of the rolled bar (25.6-27.0). The specimens 5 and 6 (tests 8-9) were milled from a 3.54 inch (90 millimeter) round bar that had not been subjected to any heat treatment.

The results of tests 4, 5, 6, 7, and 9 are graphically plotted in Fig. 1. The results of test 4 are plotted in Fig. 2 where the resistance values for both heating and cooling are shown.

As is seen in Table I and Fig. 1, the Ac₁ interval lies between the temperatures 1362-1387 degrees Fahr. (739-753 degrees Cent.), ± 1 degree, except for test 5, where the terminus of the interval

Table II
Specific Resistances at Room Temperature

No.	Previous Treatment	Max. temp. and cooling degrees Fahr.	Microhm per cm ³ /cm at room temp.	
			Before the run	After the run
1	Untreated .197-inch square. Annealed at 1256 degrees Fahr.	1418, comparatively quick cooling	26.2	27.0
2	Comparatively quick cooling from 1418 degrees Fahr.	1461, comparatively quick cooling	27.0	28.0
4	Untreated .197-inch square Annealed at 1292 degrees Fahr.	1436, slow cooling	23.5	22.3
5	Soft annealed at 1436 de- grees Fahr.	1857, comparatively quick cooling	22.3	24.9
6	Untreated .197-inch square. Annealed at 1112 degrees Fahr.	.... comparatively quick cooling	24.4	...
7	Soft annealed at 1436 de- grees Fahr.	1450, comparatively quick cooling	22.3	24.6
8	Untreated 3.54-inches round	1477, comparatively quick cooling	27.0	24.9
9	Untreated 3.54-inches round	1467, comparatively quick cooling	25.6	24.6

lies at 1396 degrees Fahr. (758 degrees Cent.) At 1389 degrees Fahr. (754 degrees Cent.) there is a slight discontinuity, not sufficiently accentuated, however, to indicate the terminus in question. Before test 5 the test piece had been soft annealed by the preceding test, and thus the constituents in the material were well diffused. This is shown by the low specific resistance at room temperature (Table II), and by the fact that the branch of the curve below the A_{c_1} interval closely follows the curves from the other tests. Test 7, was made with material soft annealed at 1436 degrees Fahr. (780 degrees Cent.) by regular annealing, shows the same low resistance at room temperature, but a somewhat less regular passage below the A_{c_1} interval. Above the A_{c_1} interval it runs, however, more regularly than the curve 5 indicates. The tests 4 and 6 (also test 1 which is not shown on the graph) were made with forged material only, subjected to a tempering process. These show a pronounced discontinuity immediately above the terminus of the A_{c_1} interval. A similar discontinuity immediately above the terminus for the

Ac_1 interval exists. A similar discontinuity, although at a higher temperature, was obtained in test 5.

If a steel that contains a considerable number of carbide forming components, such as chromium, is annealed at the proper high temperature, it is possible that at the same time as the diffu-

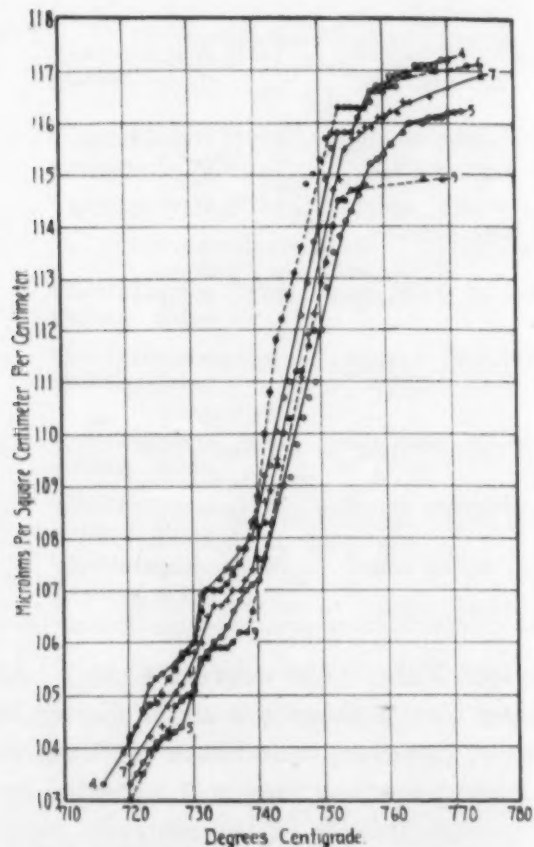


Fig. 1—Curves Obtained from the Various Tests Showing the Resistance at Different Temperatures. Steel U-887. (See Table I.)

sion takes place in the gamma iron, some changes will occur also in the still undissolved carbides.

Test 4 and 5 were made with the same specimen without changing the location in the furnace. The specific resistance obtained in test 4 at 1423 degrees Fahr. (773 degrees Cent.) is 117.3 microhms per square centimeter per centimeter², while in test 5 at the same temperature the resistance is only 116.3 microhms. Test 5 was continued to 1836 degrees Fahr. (1002 degrees Cent.),

²All electrical resistances given in this paper refer to microhms per square centimeter per centimeter. For the sake of brevity this unit will be expressed as microhms only.

1927

and the resistance at this temperature had increased to 125.4 microhms. During 12 hours the temperature was lowered to 1423 degrees Fahr. (773 degrees Cent.), when the resistance was 117.5 microhms, i. e. about the same as for test 4. The temperature was then increased for 45 minutes to 1443 degrees Fahr. (784 degrees Cent.) with the result that the resistance increased to 118.0 microhms. This indicates that the increased resistance at 1423 degrees Fahr. (773 degrees Cent.) after heating to 1836 degrees Fahr. (1002 degrees Cent.) is not due to any influence of hysteresis. The temperature was afterwards kept approximately constant at 1443 degrees Fahr. (784 degrees Cent.) for 23 hours, when the resistance had decreased to 116.0 microhms, i. e. about the same resistance as that originally obtained in test 5 after the specimens had been soft annealed.

These tests show that at a certain temperature interval a decrease in resistance will occur after a suitable annealing time. By a subsequent, suitable annealing at higher temperature with subsequent cooling, which may take place comparatively slowly, an increase in the resistance to about the same value as before will occur.

The source of these variations may be only diffusion, in which case a comparatively long time is required, or a combination of diffusion and the formation of carbides higher in chromium content, which withdraw chromium and possibly also carbon from the gamma iron. The practical conclusion is that the soft annealing temperature should not be maintained longer than necessary to get the desired decrease in hardness required for the subsequent machining operation. The greater the decrease in hardness the higher temperature will be required before the hardening quench in order to obtain the same saturation of the gamma iron. The saturation refers here directly to the resistance, and thus includes also the degree of diffusion. For practical purposes, however, it does not matter if the decrease of resistance is caused by diffusion only, or whether the decrease is caused by a combination of diffusion and formation of carbides high in chromium. At a given temperature a decrease in hardening intensity is obtained in both cases as compared to a material with higher hardness before the hardening. An essential and practical difference exists, however, when such stable carbides are formed that they will not be easily

dissolved by a reasonable heating. The author has, however, not encountered such carbides in chromium steels, but they are undoubtedly present in tungsten steels of the Allevard type (Carbon 0.55 per cent, Tungsten 5.5 per cent). In these cases the decrease in resistance corresponds undoubtedly to a lower saturation of the gamma iron.

With the steel in question it is, however, not only a diffusion effect that causes the decrease of resistance, as is proved by comparing the tests 4 and 9. The specimen in test 4 had at room temperature before the test a specific resistance of 23.5 microhms, whereas the specimen in test 9 had a resistance of 25.6 microhms. The specimen in test 4 was well worked by forging the piece from billet size to about 0.197 inch (5 millimeters) square, and then tempered at 1292 degrees Fahr. (700 degrees Cent.) For test 9 the specimen was taken from a rolled bar 3.54 inches (90 millimeters) round, by machining at room temperature. This latter specimen, thus, had been subjected to a considerably less thorough heat treatment, and had moreover not been tempered. The former specimen therefore had the constituents better diffused before the beginning of the test than in the latter one. By comparing the results shown graphically it is found that already below 1328 degrees Fahr. (720 degrees Cent.) the mutual conditions between the resistances have been reversed, so that the curve for test 4 indicates a higher resistance than the curve for test 9. The pearlite interval starts in both cases at about the same temperature, but the electrical resistance is at this point much lower in test 9 than in test 4, and the difference at the end of the pearlite interval is still considerable, showing that the gamma iron formed in test 9 is lower in chromium and carbon or possibly in chromium or carbon. At increased temperature this difference gradually disappears. Thus it is shown that the solubility of the carbides and consequently the degree of saturation of chromium and carbon by the gamma iron depends on the composition of the carbides present.

The practical result of this comparison is that coarsely grained, less carefully forged material should be heated before the soft annealing to a suitable, rather high temperature, followed by a comparatively fast cooling to below the A_{r1} interval. The following soft anneal should be carried out at the lowest possible temperature and for as short a time as possible.

From an economical point of view it might sometimes be preferable to carry out the soft anneal first, then the machining, and finally normalize the steel before hardening, as by this method less material would have to be handled in the normalizing operation before the hardening. There are, however, several factors opposed to such a sequence of operations. The coarsely grained steel after rolling or forging contains a pearlite, lower in carbon or chromium

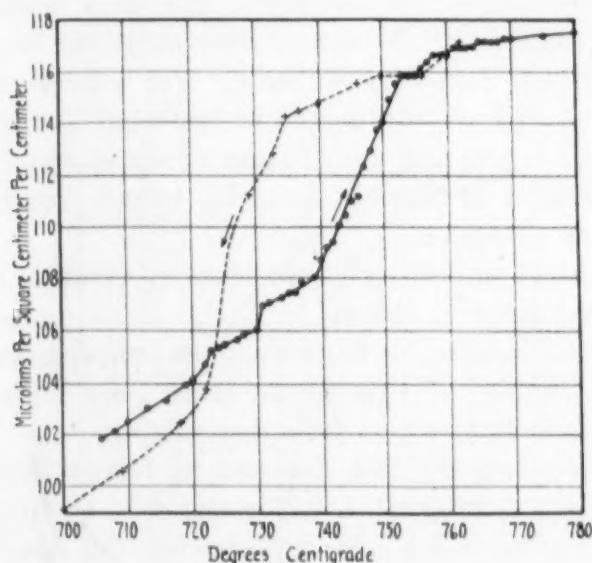


Fig. 2—Heating and Cooling Curves Obtained in Test 4. Steel U-887.

than the same material after normalizing. In order to obtain the same softness by the soft anneal after normalizing a higher annealing temperature is required, and consequently a longer time of cooling. The higher annealing temperature will also cause a still coarser structure than before, and the subsequent normalizing will not be so effective.

Fig. 2 shows the heating and cooling curves obtained in test 4, for which untreated 0.197 inch (5 millimeter-square) specimens were used. The maximum temperature was 1436 degrees Fahr. (780 degrees Cent.) and during the following cooling the pearlite was precipitated at about 1328 degrees Fahr. (720 degrees Cent.)

In the so-called pearlite anneal and still more in the anneal of hypereutectoid steels, as in this case, the main annealing, if by that is meant the softening, is of course accomplished during the cooling period and not during the heating period. By the heating and the

accompanying formation of gamma iron and spheroidizing of excess carbides the steel is prepared for annealing. The actual anneal occurs, however, only with the formation of the annealing structure. This structure again can be said to consist of one structure visible with the microscope and of one structure not visible with the microscope. The distribution of the carbides and the size of the carbide grains are characteristic of the visible structure, while the degree of diffusion within the alpha iron does not belong to the visible structure. At the same visible structure the hardness is lower with a high degree of diffusion. For a following hardening it is beneficial to have the degree of diffusion as low as possible, i. e. at a suitable size and distribution of the carbides the material should be as hard as possible, in order to give the best result in the hardening operation.

An ideal soft annealing of the steel in question should therefore be carried out as follows:

- 1 A rapid heating to the maximum temperature
- 2 Maintenance of this temperature long enough to allow excess carbides sufficient time for spheroidizing
- 3 A comparatively fast decrease of temperature to the beginning of the Ar_1 interval, i. e. for test 4 to about 1355 degrees Fahr. (735 degrees Cent.) at a maximum temperature of 1436 degrees Fahr. (780 degrees Cent.)
- 4 A slow passing (maximum 50-degrees Fahr. per hour) of the Ar_1 interval, and afterwards a more rapid cooling, which may be carried out in the air without disadvantage.

The location of the declining curve branch in Fig. 2 in relation to the inclining one at temperatures below 1328 degrees Fahr. (720 degree Cent.) shows that the material really has been softened by the soft annealing. For the inclining branch the resistance at 1310 degrees Fahr. (710 degrees Cent.) is 102.5 microhms, and for the declining one only 100.7 microhms.

With steel Y-208 three tests were made, the results of which are compiled in the Table III and Fig. 3.

For each test a new specimen was used. All the specimens were untreated after the forging and only tempered at 1292 degrees Fahr. (700 degrees Cent.)

This steel has practically the same Ac_1 interval as the former as is seen from Table III and Fig. 3.

Table III
Critical Range Temperatures

No.	A_{c1} interval degrees Fahr.	A_{r1} interval degrees Fahr.	The pearlite diffused:
1	1362-1386		
2	1362-1387	1341-1323	Completely
3	1362	1351-1342	Partially

In one case (2) the pearlite has been completely, and in another case (3) partially dissolved, and in this way the correspondence between the A_{r1} interval and the amount of dissolved gamma iron has been shown. If the temperature has been above the A_{c1}

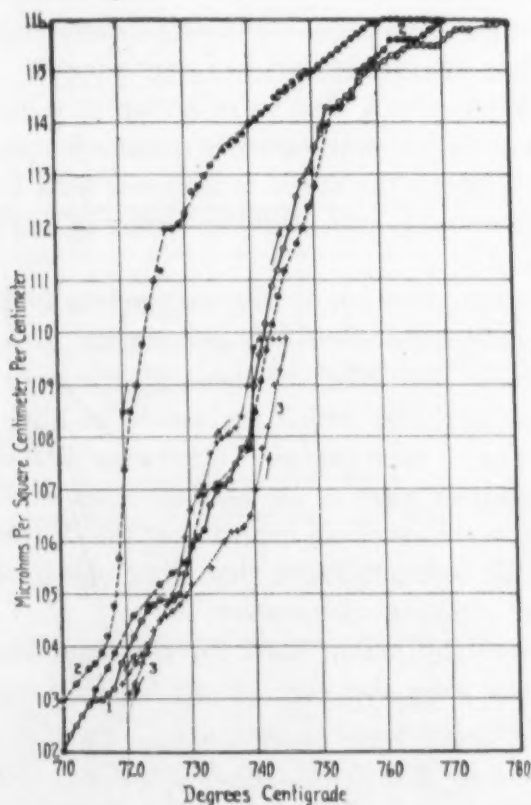


Fig. 3—Curves Showing Results of Three Tests on Steel Y-208.

interval, the A_{r1} interval starts at a somewhat lower temperature and the hysteresis area is considerably larger than if only the heating is extended partly in the A_{c1} interval.

Test 2 is performed with a somewhat higher heating and cooling speed than normal, with the result that the declining curve

branch shows a higher resistance than the inclining one at the temperatures where, after a successful soft anneal, the inversed case usually occurs.

Test 4 of U-887 and test 1 of Y-208 are comparable to each other in regard to the specimens, the execution of the tests, etc. The pearlite interval is for the former steel 1362-1387 degrees Fahr. (739-753 degrees Cent.) and for the latter 1362-1386 degrees Fahr. (739-752 degrees Cent.). At the initial point the resistance in both cases is about 108 microhms, but at the terminus U-887 shows about 116 microhms, and Y-208 about 114 microhms, i. e. in one case the solution of the pearlite has caused an increase of resistance of about 8 microhms, but in the other case only 6 microhms or 25 per cent less. In steels with high alloy contents the effect of the reactions within the pearlite interval is thus less pronounced. A smaller part of alloy constituents would thus be in action at a hardening operation from a temperature immediately above the pearlite interval. This difference between the steels is lessened with further increase of the temperature, but is still over 1 microhm at 1436 degrees Fahr. (780 degrees Cent.).

The practical application of this comparison is that an increase of the alloy constituents does not necessarily give a steel when quenched a greater hardness, if these alloying elements have a tendency to form carbides which are stable at high temperatures. These carbides may even at the otherwise suitable hardening temperature withdraw carbon as well as other alloy constituents from the gamma iron to such an extent that the degree of saturation of the gamma iron becomes lower than that obtained in steel with lower content of alloying elements.

With the same equipment used for the tests described, resistance measurements were also carried out for each steel at constant temperature within the pearlite interval. The object of this was, as earlier with the carbon steels³, to demonstrate that the pearlite intervals are actual intervals, and that the corresponding reaction cannot be completed to the total transformation of the pearlite only by prolonging the time after the reaction has started.

The results are plotted in Figs. 4 and 5. For U-887, constant resistance was obtained at 1373 degrees Fahr. (745 degrees Cent.)

³Teknisk Tidskrift, Bergsvetenskap, 1925, p. 51. TRANSACTIONS, A. S. S. T., Vol. 9, 1926, pp. 430-451.

after about 65 minutes, and for Y-208 at 1366 degrees Fahr. (741 degrees Cent.) after about 80 minutes. Previous tests on pure carbon steels showed a stable equilibrium after about 195 minutes for hypoeutectoid steel, and after about 360 minutes for hyper-eutectoid steel. This indicates that with the steels now subject to

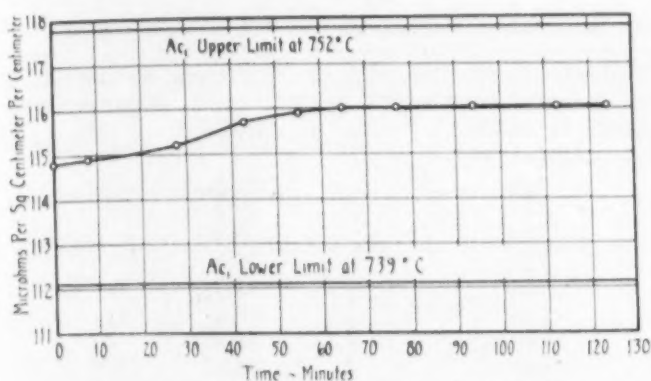


Fig. 4—Resistance-Time Curve for Steel U-887.

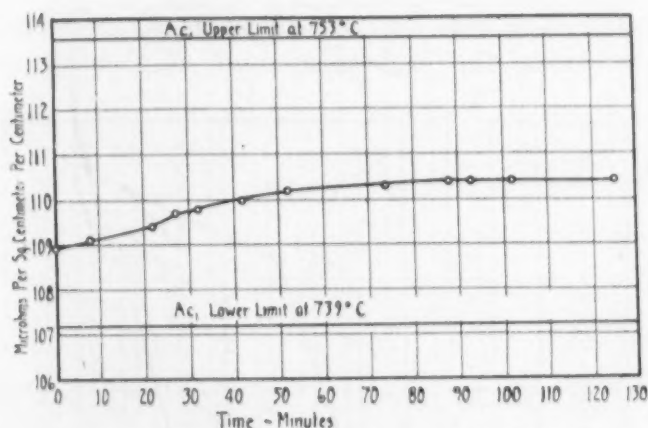


Fig. 5—Resistance-Time Curve for Steel Y-208.

investigation stable equilibrium is obtained considerably faster, which really was to be expected from the Gibb's phase rule by the introduction of a new, richly represented component.

Electrical Resistance Measurements on Specimens, Quenched in Water from Different Temperatures. The Resistance Measurements were made at Constant Temperature.

The test bars, 5.02 x .197 x .197 inches (128 x 5 x 5 millimeters), were machined and carefully ground. They were quenched in water after a heating for 10 minutes at different constant temperatures. The electrical resistance was determined at 68 degrees

Fahr. (20 degrees Cent.) and the results obtained with the different quenching temperatures are plotted in Fig. 6 and 7. (See also Table IV). In every case a test bar from each charge was heated and quenched at the same time.

Table IV
Resistance Versus Quenching Temperatures

Heated for 10 minutes at the following : temperatures, followed by a rapid quench in water		Microhms 68 degrees Fahr. (+ 20 degrees Cent. : U-887 : Y-208	
degrees Fahr.	degrees Cent.		
1292	700	22.9	22.6
1348	731	23.0	22.7
1357	736	23.1	22.8
1364	740	25.4	24.4
1387	753	33.0	30.2
1396	758	35.8	34.9
1436	780	38.0	37.9
1472	800	39.5	39.6
1508	820	42.0	42.3

The results show that here as well as in previous investigations the steel containing the highest amount of alloying components

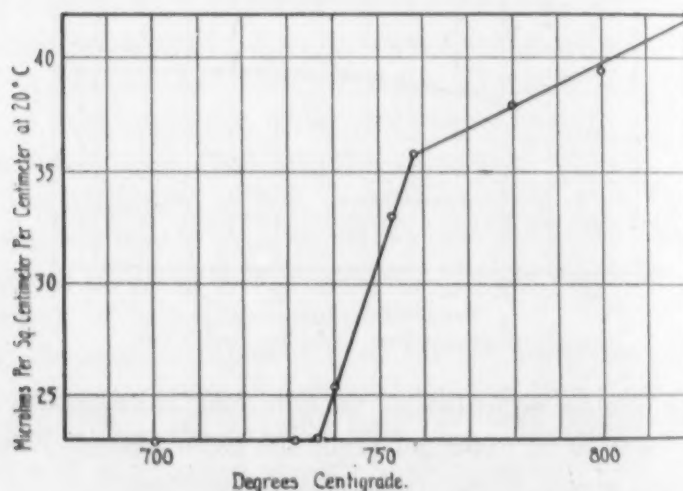


Fig. 6—Curve Showing Results Obtained with Different Quenching Temperatures on Steel U-887.

shows lower resistance immediately above the pearlite interval, and that this difference is lessened with increased temperature. It should be mentioned that this method is not suitable for an accurate determination of the actual pearlite interval. The pearlite interval as determined by this method is the same for both steels, about

1927

1357-1396 degrees Fahr. (736-758 degrees Cent.). Determined by the previous method the interval was also the same for the two steels, but included only the temperatures 1362-1387 degrees Fahr. (739-753 degrees Cent.)

The curves show that the pearlite transformation is not completed at 1508 degrees Fahr. (820 degrees Cent.) The direction of the curve indicates that the steel with the higher alloy content by continued increase of the temperature will give a considerably higher resistance than the other steel.

Benedick's formula⁴ $\delta = 7.6 + 26.8 \pm C$

gives the highest possible resistance on hardened specimens, as follows

U-887	50.7 microhms
Y-208	52.1 microhms

If these values are reached it indicates that the whole structure

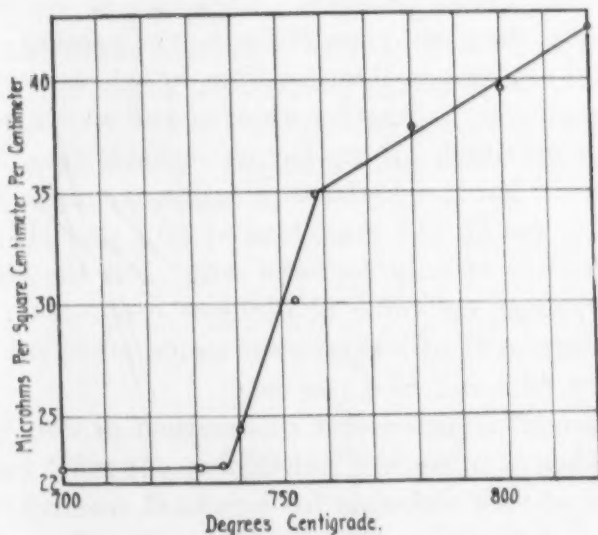


Fig. 7—Curve Showing Results Obtained with Different Quenching Temperatures on Steel Y-208.

consists of uniform martensite without carbides.

If 1436 degrees Fahr. (780 degrees Cent.) can be regarded as a suitable hardening temperature, the following differences show the resistance that so to speak has not been utilized:

U-887	50.7 — 38.0 = 12.7 microhms
Y-208	52.1 — 37.9 = 14.2 microhms

⁴Jernkontorets Annaler, p. 35, 1916.

The higher alloyed chromium-molybdenum steel thus shows a 1.5 microhm greater difference at this temperature. In order to utilize in this respect the alloys as much as in the chromium steel, a higher hardening temperature is required. At the highest temperature employed, 1508 degrees Fahr. (820 degrees Cent.) the following differences are obtained:

U-887	50.7 — 42.0 = 8.7 microhms
Y-208	52.1 — 42.3 = 9.8 microhms

This shows that still at 1508 degrees Fahr. (820 degrees Cent.) a difference of 1.1 microhms is observed between the two steels.

It has already been mentioned that greater hardness is not to be expected in a steel only by increasing the amount and number of alloying components, when these are able to form carbides stable at high temperatures. In a steel for machine parts, such as ball bearings, the carbides remaining after the hardening are presumably of insignificant importance. They are of course important in keeping down the grain growth during the heating period before hardening and are an excellent medium by which to determine by means of the microscope whether an even and well hardened structure has been obtained. Regarded as carbides they hardly, however, improve the hardened structure as far as service is concerned.

Already a loss of 12.7 microhms of 50.7 possible shows, so to speak, an efficiency of only 75.0 per cent. For the higher alloyed steel the corresponding value is 72.6 per cent. At 1508 degrees Fahr. (820 degrees Cent.) hardening temperature the corresponding figures are 82.8 and 81.0 per cent.

It is willingly admitted that this method of discussing the results of a quench is in no way exhaustive. It may, however, offer certain points of view valuable for practical research work. It is exclusively a technical-economical problem. The desire is to obtain the best possible material at the lowest possible cost. The point is, of course, not to burden the expense account with unnecessary expenses for alloying components. If a certain percentage of carbides presumably is necessary in the hardened structure, only enough alloying elements should be added so that this structure is obtained. Furthermore, the relation between the carbon content and the other alloying constituents should be so balanced that at a specified dimension and a certain hardening medium the steel contains suitable amounts of alloying constituents to insure hard-

ening throughout the structure. Hence is seen that the practical research work is extremely complicated. If a suitable excess of carbides is established, but the material proves to have insufficient through-hardening properties and the amount of alloying constituents therefore is changed, this will at the same time influence the amount of excess carbides. The above method gives, however, a possibility to study at least to some extent these changes and thus empirically arrive at a suitable result.

ANNEALING TESTS

On forged, untreated specimens from both heats with dimensions of 0.5 x 0.25 inch the following annealing tests were made. The annealing tests were carried out in a 23.62 x 2.56 inch (600 x 65 millimeter) Heraeus furnace with an inserted 2-inch steel tube. The specimens were packed in gray cast iron chips with an insulated platinum-platinum-rhodium thermocouple in a 1.75 inch steel tube fitting into the larger one. The thermocouple was the same, and connected to the same millivoltmeter that had previously been used for all the electrical resistance measurements. The current supply to the furnace was regulated by means of rheostats and controlled by an ammeter. The annealing times are shown in Table V, and the results in Table VI.

Table V
Annealing Periods

Annealing No. 1			Annealing No. 2			Annealing No. 3		
°F.	°C.	Min.	°F.	°C.	Min.	°F.	°C.	Min.
1371	744	0	1400	760	0	1472	800	0
1369	743	60	1398	759	53	1472	800	120
1364	740	140	1400	760	140	1458	792	145
1359	737	155	1387	753	160	1436	780	280
1353	734	175	1380	749	195	1420	771	304
1346	730	227	1375	746	205	1400	760	344
1341	727	255	1355	735	240	1378	748	412
1335	724	265	1344	729	270	1382	750	532
1321	716	320	1328	720	330	1310	710	1297
1310	710	375	1319	715	350	1274	690	1452
1292	700	415	1305	707	420			
The current broken			The current broken			The current broken		

Annealing tests were also made on 3.54 inch (90 millimeter) specimens, untreated after rolling, from steel U-887. See Table VII.

The microstructures of all specimens, belonging to Table VI,

were practically the same with spheroidized carbides in ferrite. The microscopic structure of samples from charge U-887 after anneal-

Table VI
Hardness Results after Annealing

Annealing Temp. °F. °C.		Ball indentation, 10 mm. ball, 3000 kgs. mm.		Hardness number according to Brinell	
		U-887	Y-208	U-887	Y-208
1371	744	4.50	4.45	179	183
1400	760	4.45	4.40	183	187
1472	800	4.40	4.50	187	179

ing to 1400 degrees Fahr. (760 degrees Cent.) is shown in Fig. 8 (etching reagent nitric acid, 500 diameters magnification).

In regard to the annealing operation it should further be mentioned that the usually employed annealing temperature for these steels, about 1436 degrees Fahr. (780 degrees Cent.) is unneces-

Table VII

Annealing Temp. degrees Fahr.		Ball indentation, mm. 10 mm. ball, 3000 kgs.	Hardness number according to Brinell
1369	743	4.30	197
1526	830	4.40	187

sarily high and that the most important temperature range during the cooling seems to be between about 1364 and 1328 degrees Fahr.

HARDENING TESTS

The hardening tests were performed on $\frac{1}{2}$ inch x $\frac{1}{4}$ inch annealed specimens. Before the hardening about 1 mm was removed from the test pieces by filing in order to insure that all decarburization was removed. One specimen from each charge was hardened at the same time, the heating being made in a silica tube that could be removed from the furnace. The hardening was performed in water after 5 minutes at constant maximum temperature. The Brinell hardness determinations were carried out with a 3000 kilogram load and a 10 mm "Hultgren's ball". In order to obtain correct readings the specimens were highly polished before making the hardness tests. Rockwell tests with diamond cone were also made on the same specimens. The results from the tests are compiled in Table VIII.

Table VIII
Hardness Tests

Previous treatm. of the specimens			Hardening in water			
Annealing temp. °Fahr.	Brinell number		Hardening temp. °Fahr.	Brinell number	Rockwell C	
	Y-208	U-887		U-887	Y-208	U-887
1371	179	183	1418	706	676	63.5
1371	179	183	1436	712	712	64.0
1371	179	183	1508	712	712	65.3
1371	179	183	1544	712	712	66.0
1472	187	179	1418	653	653	62.0
1472	187	179	1436	682	682	62.5
Then normalized from			1418	682	682	64.2
1472 deg. Fahr...			1436	712	712	64.3
800 degrees Cent.						65.0

The investigations show that full hardness, even with so small specimens as $\frac{1}{2} \times \frac{1}{4}$ inch, is not reached by quenching in water at

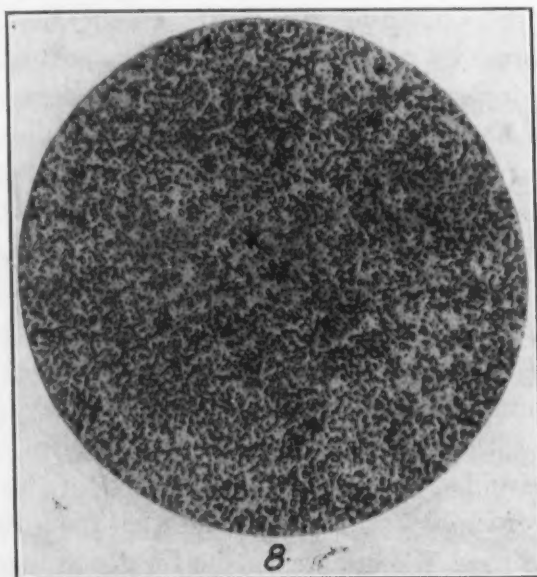


Fig. 8—Photomicrograph of Sample from Steel U-887 After Annealing. Etched with Nitric Acid. 500x.

lower temperature than about 1436 degrees Fahr. (780 degrees Cent.) This is true only if the steel is annealed at low temperature. On the contrary, if the annealing temperature is increased, still higher hardening temperatures are required in order to attain maximum hardness. The results further indicate the influence of normalizing where the steel previously had been annealed at high

temperatures. With normalized test pieces full hardness is already obtained at a hardening temperature of 1436 degrees Fahr.

The specimens annealed at low temperature show at the lowest possible hardening temperature a somewhat lower hardness for the steel highest in alloy content, a fact that could be expected from the previous discussion of the specific resistance.

SUMMARY

Two ball bearing steels have been the subject of thermal investigations. One of these was of the common type. The other had a higher content of chromium, and contained some molybdenum.

The A_{c1} interval for the two steels was the same, i. e. between 1362 and 1387 degrees Fahr. (739 and 753 degrees Cent.)

The influence of the anneal on the subsequent hardening has been discussed in connection with the normalizing of the material. The possibility of obtaining an improvement in the quality of coarse grained steel by normalizing before the soft anneal has been discussed. The importance of using as low an annealing temperature as possible has been stressed. If the annealing temperature has been comparatively low, the subsequent hardening can take place at a correspondingly lower temperature and the same hardness will still be obtained.

The structure of the steel, after the anneal may be said to be one that is visible and one that is invisible under the microscope. As far as the mechanical working of the steel is concerned, the first of these is of dominating importance. The visible structure shows the carbides and their distribution in the ferrite. The carbides should be well rounded and evenly distributed in the matrix. The microscopically invisible structure refers to the diffusion of the chromium, manganese, silicon, etc. in the ferrite grains. The higher the annealing temperature, at least below a definite maximum value, i. e. which is considerably higher than the proper annealing temperature, and the slower the cooling has taken place, the more completely the alloys in the steel are distributed within the ferrite. A steel in this condition with the alloys evenly diffused will at a subsequent hardening give a comparatively low hardness. It can reasonably be assumed that the ferrite will become lower in chromium by the formation of carbides high in chromium, and these carbides will during the cooling absorb some of the chromium in the ferrite. If

the steel has been annealed by this improper method, the subsequent heating for hardening will give a gamma iron low in chromium and carbon or possibly in chromium or carbon, as compared to the steel that has been subjected to a proper annealing at a lower temperature. The result of the hardening will, therefore, be a softer steel with grains of martensite of rather large size. The matrix should, therefore, be as rich in alloying elements as possible. These should be diffused to the least possible degree. The effect of this will be a greater hardness after the anneal. Consequently, at a suitable visible annealing structure the steel should be as hard as possible in order to give the best results in the hardening operation.

By means of electrical resistance measurements at constant temperature on test pieces that have been quenched in water from different temperatures it has been shown that it is possible to determine how great is the percentage of the alloying elements in the steel that are effective at the hardening. On the basis of Benedick's formula $\delta = 7.6 + 26.8 \pm C$, it is possible to determine a percentage of efficiency for the different steels. The highest specific theoretical resistance for a certain steel is calculated by means of this formula and by means of this value and the resistance determined after hardening from different temperatures the percentage efficiency is calculated. It is shown that this percentage of efficiency will be lowered by the addition of too great an amount of alloying elements or by too high a percentage of carbon, due to the fact that the alloying elements have the ability to form stable carbides at temperatures above the A_{c1} interval. There is, therefore, by means of this method a possibility to study the analyses of the steels and, in a way, calculate the percentage of efficiency of the different analyses at suitable hardening temperatures. This method, therefore, affords a possibility to determine the most suitable, i. e. the cheapest analyses for definite mechanical properties with certain definite hardening methods. It should, therefore, be possible, by means of this method, to eliminate several of the now complicated and often not understandable analyses of steels and it should also be possible, in certain cases, to obtain a considerably cheaper steel, while maintaining or raising the quality of the mechanical properties.

A CRITICAL STUDY OF THE BEND TEST AS APPLIED TO IRON AND STEEL

BY A. B. KINZEL

Abstract

This paper includes a theoretical study of the strains produced on bending a rectangular bar. From the theory there is deduced a method for the quantitative evaluation of a bend test. The phenomena of inside crack is investigated and the relation between tensile and bend elongation is discussed. Specifications for routine quantitative bend testing are given together with precautions and limiting factors involved.

IN BENDING a bar, tension stresses are set up in the outer fibers and compression stresses in the inner fibers. Between the two a plane of no stress exists known as the neutral axis. The stresses set up in a straight rectangular bar subjected to bending moments have been thoroughly analyzed both mathematically and by means of strain gage measurements. The position of the neutral axis has been established and is identical with the plane of the center of gravity of the bar and the stress has been shown to vary directly as the distance from this plane. In the case of bars which are curved or which assume a marked curvature during the application of the bending moment, the neutral axis is displaced and the stress distribution is hyperbolic. The mathematical theory of curved bars is fairly complex, and will not be given here. A detailed discussion may be found in any of the more advanced books on the strength of materials.

OBJECT OF THE PAPER

Inasmuch as the bend test is used extensively in the physical testing of iron and steel, the author has made a study of the subject with a view to developing certain formulae which will aid the testing engineer to more intelligently interpret the results of tests by the bending method. While the discussion which follows is of a semi-theoretical nature, a brief study will reveal the logic used and the practical application of the formulae and the methods described.

A paper presented before the ninth annual convention of the society held in Detroit, September 19 to 23, 1927. The author, A. B. Kinzel, a member of the society, is a member of the staff of the Union Carbide and Carbon Research Laboratories, Inc., Long Island City, New York. Manuscript received July 18, 1927.

C.G. = plane of center of gravity of the bar

N.A. = neutral axis of the bar

l = unit length of bar

 Δ = elongation in the outer fiber, due to change in radius of curvature of the center of gravity

y = distance from neutral axis

r = radius of neutral axis

R = radius of center of gravity

Z = displacement of neutral axis

t = thickness of bar

e = fractional elongation; ratio of elongation to unit length

It has been shown (Timoshenko's Elasticity) that the displacement of the neutral axis from the center of gravity may be expressed by two factors, one of them being a series.

Generally we may neglect the third term and all subsequent terms of this series whence

$$Z = \frac{t^2}{12R}$$

Substituting the value of Z in the above equations and dividing one by the other,

$$\frac{y}{r} = \frac{\frac{t}{2} + \frac{t^2}{12R}}{R - \frac{t^2}{12R}}$$

If we express R in terms of t, $R = xt$ and $x = \frac{R}{t}$. Thus, x is the ratio of the radius of curvature of the center of gravity to the thickness of the bar. Then

$$e = \frac{6x + 1}{12x^2 - 1} \quad \text{Fundamental formula} \quad (3)$$

which is the elongation of the outside fiber expressed in terms of the ratio of the radius of curvature of the center of gravity to the thickness of the bar. The following table shows some computed values. This function is almost linear over the usual range when plotted logarithmically, Fig. 3.

SPECIAL APPLICATION OF FORMULA

It will be seen that for bends of large radius of curvature the value x in the formula is very large compared to the 1. If we neglect the 1 in the numerator and denominator we have

$$e = \frac{1}{2x} \quad \text{or} \quad \frac{t}{2R} \quad (4)$$

X	$6x + 1$	$12x^2 - 1$	e	log. e	log. X
500	3001	2,999,999	.001	—3	2.699
100	601	119,999	.005	—2.30	2.
20	121	4,799	.025	—1.603	1.301
10	61	1,100	.050	—1.301	1.
5	31	299	.006	—1	.699
4	25	191	.131	— .887	.602
3	19	107	.176	— .755	.477
2	13	47	.282	— .55	.301
1	7	11	.636	— .20	0
0.5	4	2	2.00	+0.30	— .301

It will be seen that this is the formula neglecting neutral axis displacements and under certain circumstances is sufficiently accurate.

The figures in the table show when permanent set occurs in the material. With a given elastic limit, e.g., 30,000 pounds per square inch the material yields when the radius of curvature is

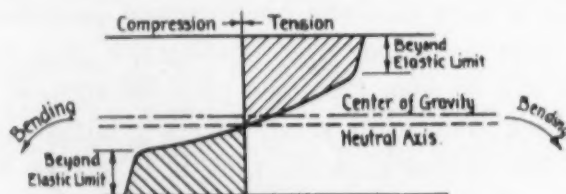


Fig. 2—Stress Distribution Across Bent Bar.

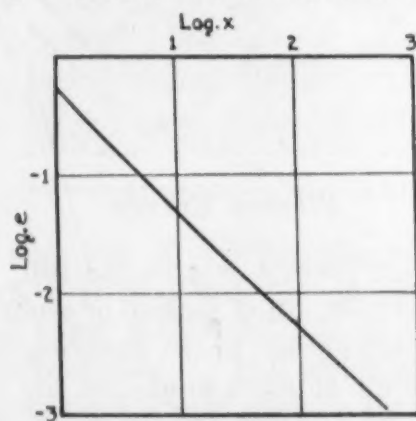


Fig. 3—Logarithmic Graph of

$$e = \frac{6x + 1}{12x^2 - 1}$$

five hundred times the thickness or less. We also see that the usual bend test is carried on almost entirely beyond the elastic limit and that the theory of elasticity will yield little as to the fiber stress involved due to the lack of constant ratio between

stress and strain. In fact, in the usual test the load is not measured. There is simply enough load applied to produce the bend required. Whether or not the piece fractures is then a matter of ductility and if the piece were twice as strong, that is, the fiber stress at rupture twice as high for the same ductility, the bend test would not show it.

CRACKS ON INNER SURFACE OF SPECIMEN

In the case of extreme ductility there is an additional effect. The compressive force at the inside, due to the very great displacement of the neutral axis when the bar assumes a small radius of curvature, may become sufficiently great so that failure occurs on the inside in shear due to this compressive force, instead of failure in tension on the outside fiber. This in itself is sufficient proof of the satisfactory performance of the specimen and it is interesting to note that the phenomenon is entirely consistent with theory. The accompanying photograph Fig. 4 shows such a fracture. It will be seen from the photomicrograph 4A that the start of the crack occurs on small facets inclined approximately 45 degrees to the radius showing that it is a true shear failure. The crack then seems to take a straight course along the radius. This further development of the crack occurs under the release of pressure, the spring in the bar being sufficient to produce local stress at the end of the initial crack sufficient to cause the crack to progress further into the bar.

POISSON EFFECT

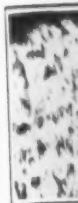
The Poisson effect plays a role in the test. A bar of elastic material subjected to stress, either tension or compression, undergoes a change in cross section normal to the direction of this stress. This is due to strains set up at right angles to the stress, contractive right angle strain in the case of tension on the bar and tensional strain in the case of compression. This is analogous to the distribution of pressure in a liquid. In any given case there is a definite ratio between the main stress and the stresses induced at right angles. This is customarily called Poisson's ratio, and is considered as fairly constant for any given material.

Were it not for this effect the width of the specimens used

1927

would no
inside su
(Photogr
traction

in tensi
the inn
result i



face o
is less
in wi
stress
Beyond
ments
ness o
minin
Poisson
incre

has o

would not be a factor. Due to these forces the metal flows at the inside surface of the bend and piles up at the sides of the bars. (Photograph Fig. 5). In addition, there is a general radial contraction of cross-section of the outside portion of the bar which is

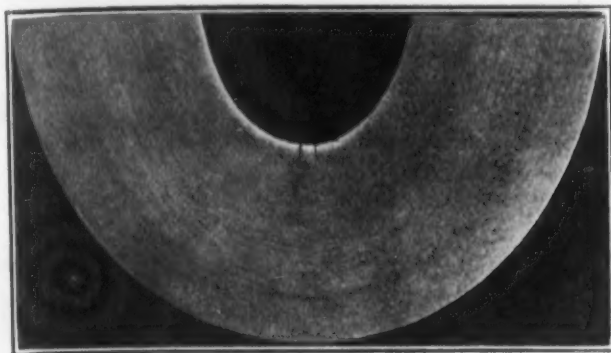


Fig. 4—Photograph (Actual Size) of Cross-Section of Bend Test Specimen, Deep Etched to Show Radial Cracks at the Inner Surface.

in tension. However, at the sides where the metal has piled up on the inner surface of the bar, radial contraction is prevented. The result is a bowed cross-section line along the outside curved sur-



Fig. 4a—Photomicrograph Showing Start of Radial Crack.

face of the bar. (See Fig. 6). When the width of the specimen is less than a certain critical width comparatively small changes in width seriously affect the results due to the difference in the stresses resulting from flow of the metal at the side surfaces. Beyond a certain critical width there is no difference. Experiments show this critical width to be about three times the thickness of the specimen and for specification tests some such standard minimum ratio of width to thickness should be assumed. The Poisson effect will be greater as the ductility of the test piece increases but will be constant for any thickness radius ratio.

The behavior of material under 1, 2 and 3 dimensional stress has often been commented upon although no definite conclusions



Fig. 5—Photograph Twice Actual Size of Bend Test Specimen Sliced in Half. View Shows Inner Curved Surface. Note the Cracks and the Lüders Lines.

have been drawn. In this connection it is interesting to note that failure invariably occurs in the center of the outside curved surface, (a, Fig. 6) even though the elongation at the edges (b), of this outside curved surface is somewhat greater. The center fibers are undoubtedly in two dimensional stress whereas the outer fibers are subjected to uni-dimensional stress.

Table
% Elongation in Bend Test of Bars of Two Steels and of Various Dimensions

Width	Thickness	Material	Bend Value	
			A.	B.
.25	.25		48	
.50			44	82
.75			37	75
1.00			39	74
1.50			39	77
2.00	.475		37	72
.50			46	
.75			44	80
1.00			39	75
1.50			38	70
2.00	.50		40	74
.75			45	
1.00			43	
1.50			39	71
2.00			39	74
.75	.75		46	
1.50			42	
2.50			37	
3.00			38	

Note that when the width is at least three times the thickness check results are obtained on the same material.

Tests
ductility
that when
test is eq



Fig. 6—
Shape Assu
angular Bar

within t
ratio, p
apparen

DEVELO

In
princip
applied
of curv
bends
perform
advisal
piece
shape
at the
elastic
length
origin
matic
here.
specia
assum

Tests were carried out on a number of samples of varying ductility and with constant width-thickness ratio. It was found that when the ratio of the width-thickness at the completion of the test is equal to or greater than three, the results are comparable

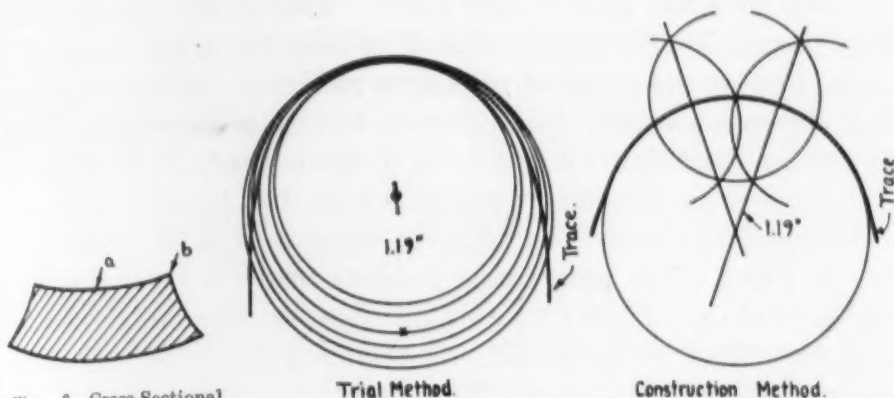


Fig. 6—Cross-Sectional Shape Assumed by Rectangular Bar on Bending.

Fig. 7—Determination of Radius of Curvature—Right, Construction Method; Left—Trial Method.

within the ordinary experimental error; but that with a smaller ratio, particularly in the cases of the more ductile materials, the apparent ductility is much better with the narrower pieces.

DEVELOPMENT AND SPECIFICATION FOR A QUANTITATIVE BEND TEST

In order to carry out bend tests intelligently there are certain principles gleaned from the previous discussion which must be applied. First, the elongation is a direct function of the radius of curvature at any point so that all local kinks or other sharp bends must be either avoided or considered in evaluating the performance of the piece. It is difficult to evaluate these so it is advisable to eliminate them as much as possible. In bending a piece freely, as previously defined, it assumes the approximate shape of an elastica and the minimum radius of curvature occurs at the center of the bend. The elastica is the curve taken by an elastic bar when the ends are subjected to a couple. For a given length and given angle which the ends of the bar make with the original axis the shape assumed by the bar is fixed. The mathematics of the elastica is quite involved and will not be gone into here. A treatment may be found in Prescott's *Elasticity*. As a special case of this when the ends of the bar are parallel the shape assumed by the curved section approximates a circle and the

diameter approximates the distance between the parallel sides, always assuming that we are within the elastic limit. This is true of thin spring steel, but generally the yield point is exceeded. In considering the ordinary stress-strain diagram of steel we note the drop in stress at the yield point. This means that the outer fibers elongate considerably as soon as they reach this stress. This occurs first at the point of minimum radius of curvature and the fiber elongation causes this radius to become even smaller. Thus, we have a condition conducive to a sharp bend. The fibers are strengthened on subsequent elongation so that their stress is once again equal to that of the adjacent fibers and sharp bending occurs in these. This progressive yielding tends to lessen the sharp local curvature. In the case of non-ferrous material there is no yield point and no accompanying tendency to sharp local curvature on bend test.

A practical and convenient bend test for quantitatively evaluating the performance of the bar has been worked out based on the above theory. It is carried out as follows: Select a section whose width is equal to or greater than three times its thickness and of sufficient length that it may be conveniently handled. Be sure that no transverse scratches exist to induce local stresses. Strike the ends with a hammer to start bending, keeping the center of the bar rigid in a vise or by other suitable means. As the final bend will occur in the center section, the hammering will not affect the results. Place the slightly bent bar in a vise or press and apply the pressure normal to the original center line of the bar, increasing the pressure until the first signs of distress or fine fracture appear on the outer surface. Fit a templet to the surface where the fracture has occurred. For some work this templet should be fitted while the bar is under pressure but in most practical applications the spring back may be neglected. The curve of the outer surface may also be obtained by tracing it on a sheet of paper after release of the load. Fig. 7. This involves a slight difficulty due to the general deformation of the sample but with very little practice a satisfactory trace of the surface may be obtained. Apply compasses to this trace and read off the minimum radius of curvature and from this obtain the radius of the center of gravity. Substitute this in the previously developed fundamental formula (3, 4) and the resulting figure is

1927

the actual elongation of the outside fibers and is a quantitative measure of the performance of the bar in bend test.

The accuracy of this test depends upon the accuracy with which the minimum radius is determined. To find out the order of this determination test pieces were marked off in $\frac{1}{8}$ inch gage

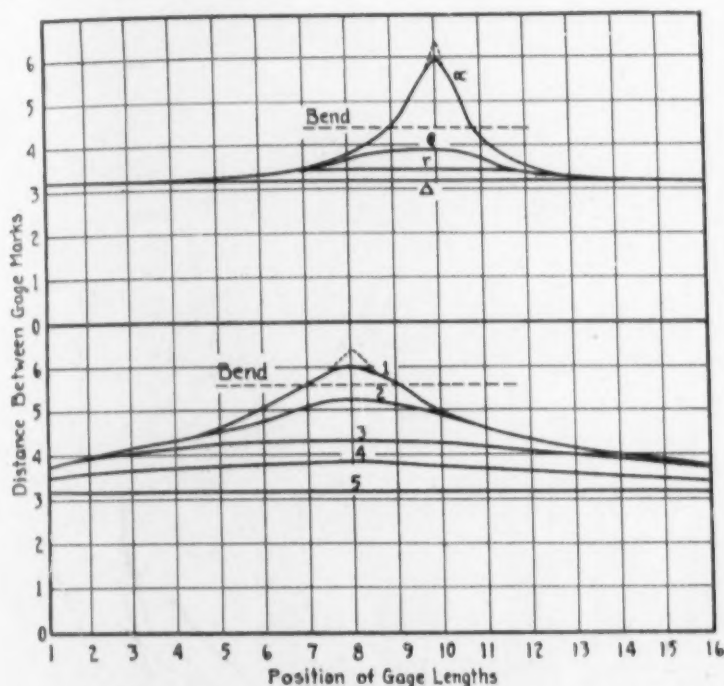


Fig. 8—Elongation in $\frac{1}{8}$ -Inch Gage Length (3.2 Millimeters) on Flat Tensile Test Specimens. The Upper Curve is Material A. The Lower Curve is Material B. The Load in Pounds Per Square Inch on Original Section for Each Curve is: Material A— α -64,000, β -83,000, γ -75,000 and δ -0. Material B—1.-46,000, 2.-47,000, 3.-53,000, 4.-52,000 and 5.-0.

lengths and then bend tested. The actual elongation of these gage lengths was then measured with a flexible scale, reading directly to sixty-fourths. A magnifying glass was used to assist in reading. The value as obtained from the radius of curvature checked the actually found elongation very closely; in fact, as close as actual readings checked each other.

ELONGATION IN TENSILE TEST AND BEND TEST

In an attempt to correlate the figure for elongation in the outside fiber obtained in the bend test with elongation in tensile test, test pieces were marked at $\frac{1}{8}$ inch gage lengths and readings taken on these gage lengths at various loadings throughout the test. A Brinell reading microscope was used for this. Materials

which showed 50 per cent elongation and 11 per cent elongation (2 inch), respectively, were chosen. See photograph Fig. 9. The accompanying curves Fig. 8 show the results obtained and the accompanying photograph Fig. 10 shows the way in which one of these pieces necked down. The photograph was taken immedi-

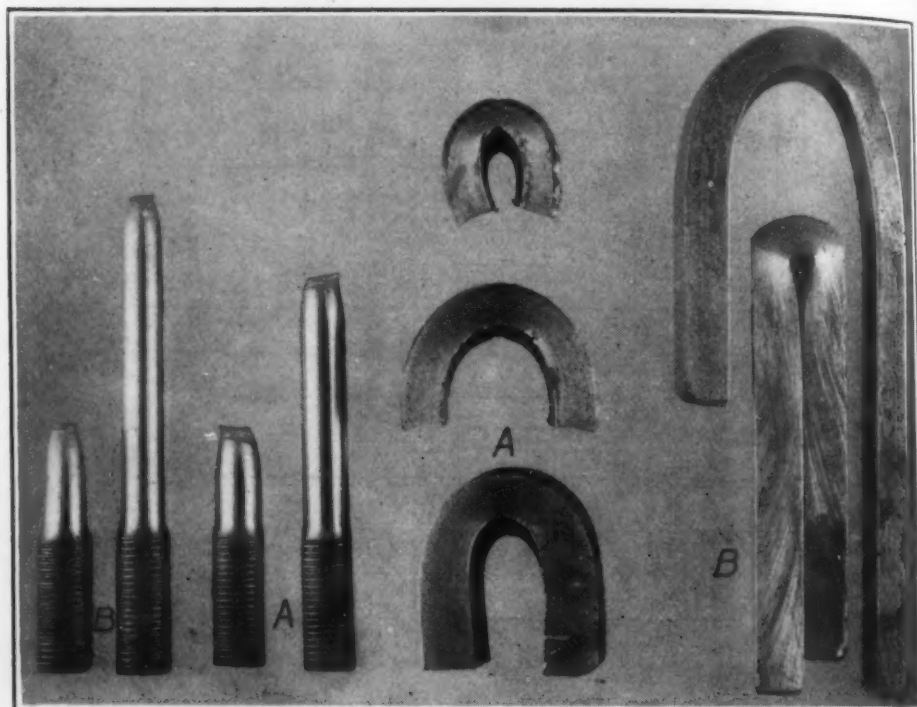


Fig. 9—Photograph Showing Comparison of Tensile Test Specimen and Bend Test Specimen of Materials A and B. Note Weld Specimen in Upper Center.

ately before fracture. From these curves it may be seen that the local elongation of the two pieces is almost the same but that the elongation immediately adjacent to this falls off very rapidly. Note that we have a local elongation of about 94 per cent whereas in the bend test the elongation of 75 per cent was reached in the case of the more ductile and 38 per cent in the case of the less ductile material. By drawing a horizontal line as shown in Fig. 8, at the point corresponding to this bend test elongation we note that the width of the sample included in the intersection of this line with the curve is slightly greater in the case of the more ductile material. This indicates that the effective width of the minimum radius of the bend corresponds to a gage length of about $\frac{3}{8}$ inch in the tensile test specimen for this material and the

difference in the nature of the curves is shown in the results obtained on the bend test. In pulling a tensile bar the total load is the same throughout the length of the bar and the instant we have contraction of cross-section the stress at this point is increased. In the bend test, however, due to the distribution of the bending moments, extremely local contraction is negligible. Thus the results of the bend test may be correlated with the tensile

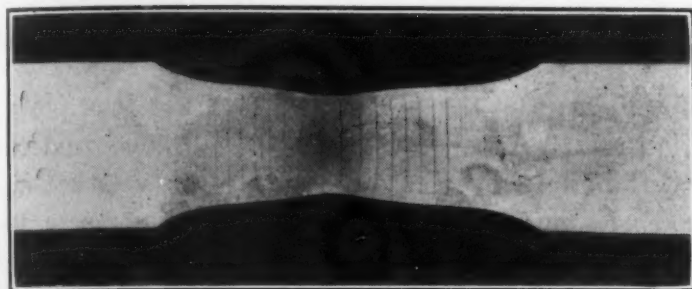


Fig. 10—Tensile Test Specimen of Material B Originally Marked Off in $\frac{1}{4}$ -Inch Gage Lengths. Photograph Immediately Before Fracture.

test by choosing the proper gage length for elongation. This gives another method for the determination of the radius of curvature, viz., to take the center point of the traced curves and a point a distance one thickness to each side and draw a circle in the customary manner. (Fig. 7) It is interesting to see that in each case actually carried out these three point circles practically coincide with the estimated minimum circle. In the table values are given from a number of individual tests.

APPLICATION OF ABOVE THEORY TO PRESENT METHODS OF BEND TESTING

In connection with this work several types of cold bend testing machines were investigated. Each of these was found to do exactly what it was supposed to do, namely, bend the bar under a set of standard conditions and give relative values on bars of identical dimensions. In general this is sufficient to tell whether or not the material is satisfactory for a given purpose. The type in most general use consists of an arrangement by which one end of the bar is fixed and the other end is bent around a pin. Attempts have been made to express the performance of the bar quantitatively as a function of the size of the pin and angle of

bend. As the bar does not take the same radius as the pin about which it is being bent the performance cannot be expressed in the above terms. The bar takes a free bend depending upon its own stress-strain characteristics. For a quantitative measure of the performance of the bar the herein described method may be applied after bending in the machine. Another type of machine consists of two fixed supports, preferably rollers, and a movable pin which pushes the center of the sample between the supports. Here again with similar pieces relative values may be obtained and this test too is of considerable value to industry. However, any attempt to express the performance of the bar quantitatively as a function of the distance between the supports and the size of the pin and the angle of bend fails due to the fact that once again the bar takes its own free bend which does not seem to depend particularly on the above factors. Here again the performance may be evaluated after bending in this machine by application of the herein described method.

DISCUSSION

It is interesting to note the deformation of the piece in tension or in bend. Theoretically a stress has a normal component of about one-third its value in steel (Poisson's ratio). It is highly probable that the value of the ratio is a variable and is some function of the ductility increasing with the ductility so that its effect is much more marked in the case of ductile samples. This action explains the shapes assumed as shown in the photographs.

The above discussion of bending applies to homogeneous material. In the case of non-homogeneous material, the situation is not materially altered. The piece may be bent so as to throw the minimum curvature into any desired portion and the above laws applied. The testing of a weld is a good illustration of this. In general, the weld is wide enough so that bending may take place entirely in the weld, if so desired, or the minimum radius may be very easily thrown to the point where the weld and the plate unite. Even with comparatively mild material with stiff welds this is true. A great many tests of welds have been made using this method. These will be reported to the American Welding Society by Mr. W. B. Miller.

PRECAUTIONS

There are two major precautions to take in the performance of a bend test. The bar may be bent in any machine in any way whatever and evaluated by measuring the radius provided that during bending the bar is not in tension. In this case the radius of curvature is not a measure of the outside fiber stress and the results are invalidated. There should be no sharp transverse scratches as failure then occurs due to a local fiber elongation which is not a known function of the radius of curvature. For practical purposes it is not necessary to bend the bar to destruction. Limits may be set and tests applied based on the above theory. Should the above method of testing be used sufficiently, tables could be provided so that the value of the outside fiber elongation could be obtained directly from the data without the direct use of any formula.

CONCLUSIONS

The above method of testing seems much more rational than those now in use as it is based on that particular property of the material which causes failure in the bend test, namely, fiber elongation.

The above theory gives us a quantitative measure of a bend. It has been developed mainly for iron and steel and thoroughly checked on this material. It should hold equally well for non-ferrous material, and the few tests which have been made on copper, bronze and aluminum, show this to be the case. However, with non-ferrous materials we are generally concerned with more than simply bending a piece upon itself and this, of course, is the limit of the type of test herein described.

DISCUSSION

Written Discussion: By E. F. Kinney, Bethlehem Steel Company, Bethlehem, Pa.

I was particularly interested in the author's remarks regarding the formation of cracks on the inner surface of the bent specimen, but am not sure that my understanding of the development of these cracks is the same as his. I realize that this feature is not an essential part of Mr. Kinzel's paper, and is not of great importance in the bend test, since the interior cracking is not used as a basis for determining the success or failure of the bend.

For that reason I am not presenting this as a formal discussion, but simply a contribution of experience on a most interesting feature touched on by the author.

It has been my experience that the crack on the inside of the bend does not take place until the load is released. It is quite possible to hear a sharp click if one stands close to the press. Under the microscope the metal which has been subjected to compression, shows crystals much extended normal to pressure, tending to the formation of planes of cleavage. It is precisely the same condition as exists in upsetting of metal in upsetting the heads of nails in manufacture. Metal distorted in this way has little resistance to tension in the direction of the original compression. It is curious how far reaching this impairment of ductility, due to compressive distortion, extends.

Manufacturers who use galvanized bars or rods which are bent in the course of forming into shape, and which forming is later trued up by adjustment of the bend, have been troubled by breakage in the slight opening of the bend, which is necessary in later adjustment. The upsetting of the metal on the inner side of the bend, impairs its ability to withstand extension in tension. Undoubtedly the metal has been affected by the pickling and the galvanizing, but it will withstand further bending in the same direction without failure, yet it is quite likely to break as soon as the bend is reversed.

Written Discussion: By G. H. Wright, testing laboratory, General Electric Company, Schenectady, N. Y.

The author is to be complimented on his splendid paper which must have entailed considerable thought and experimental work, but the author has not told us what is the practical or commercial value of the bend test over the regular standard tension test usually made on steels. We agree that the moduli of elasticity of all steels are approximately equal, but when the elastic limit has been exceeded, the results will be different.

From a commercial or design standpoint, we are not interested in deformation beyond the elastic limit other than that such properties are indicative of changes in manufacture from standard practice or changes of composition and it is not clear as to whether the bend test is to supplant any of our present standard tests. If it does not, it would seem that it is only an additional test to check data already secured.

If the author has another conception of the possibilities of the bend test, we would be interested to learn what they are.

Oral Discussion

J. M. LESSELLS: We are very much indebted to Mr. Kinzel for this interesting paper. To my knowledge, it is the first time that we have had a paper of this kind making the bend test a little more than a routine test. There has been a serious attempt here to analyze the mechanics of the bend test.

In Fig. 6, we see a cross-sectional shape assumed by a rectangular bar on bending, and fracture is indicated by position (a) on the sketch, which is the outside of the bar. I might suggest here that this fracture to the outside may have occurred due to the suppression of lateral contraction. The material at the point 'a' is not allowed to expand or contract the same as the rest of the material at point 'b', and we have here an analogous case to a brittle material. We know that in ductile materials, if we suppress lateral

contraction, we can get a brittle fracture, so I am giving this as a possible explanation of why these fractures occurred.

Mr. Kinzel mentions in the second and third third line "Between the two a plane of no stress exists known as the neutral axis." I think Professor Moore will probably support me when I say that the neutral axis is probably looked upon as the intersection of this plane with the cross-section.

Under the heading, "Cracks on Inner Surface of Specimen," we read, "—the very great displacement of the neutral axis when the bar assumes a small radius of curvature, may become sufficiently great so that failure occurs on the inside in shear due to this compressive force." Again I draw the author's attention to the fact that as a bar of this kind is bent, the neutral axis moves toward the inside. If we have a bar of this kind, the neutral axis tends to move in here, and as the neutral axis moves in towards the inside, since the stress is proportional to the distance from the neutral axis, the stress must be less.

Under the heading, "Poisson Effect," the author states, "In any given case there is a definite ratio between the main stress and the stresses induced at right angles. This is customarily called Poisson's ratio." Now, I might point out here again that Poisson's ratio, at least, I have always been taught this, is the ratio of the strains and not of the stresses. In other words, if we have a material test piece subjected to tension then the stress at right angles to this is zero, but if we have a strain in a longitudinal direction we must also have a strain at right angles to that, so Poisson's ratio is the ratio of these strains.

Then, directly following the above quotation we read, "Due to these forces the metal flows at the inside surface of the bend and piles up at the sides of the bars." I am not very clear on this myself, and perhaps Mr. Kinzel would give us further elucidation on this point. If he is still referring to these forces as due to these transverse strains, then I can not agree with him, because here we are dealing with a state of materials far beyond the elastic limit and we can only talk about Poisson's ratio provided we are within the limit of elasticity.

A. B. KINZEL: Regarding Mr. Kinney's conception of the cause of the inside crack, Mr. Kinney and I agree perfectly. I am attempting to explain the cause and mechanism of the phenomena showing the small, incipient cracks which are not visible to the unaided eye and which occur in compression. These are the real cause of the apparently brittle condition of the material when the portion previously in compression is put in tension.

Regarding Mr. Wright's discussion, he asks, "What of it?" as it were, regarding the bend test. In design at the present time we first take into consideration ultimate strength; sometimes a designer will give some consideration to yield point. Nowhere in the actual calculations on pieces are reduction of area or elongation taken into consideration. Yet, these are factors, they are prime factors, and no engineer would use a material with satisfactory yield and ultimate which had practically no elongation and no reduction of area. In choosing the value to use for his calculations, the

(Continued on Page 826)

DESIGN FROM THE HEAT TREATING STANDPOINT

BY G. M. EATON

Abstract

The author stresses the need for closer co-operation between the metallurgist and the mechanical engineer. Heretofore, each man worked principally in his own field, thus leaving many problems unsolved which might have been eliminated if there had been a closer union between the metallurgical and mechanical fields. The author gives some typical problems still unsolved because of this lack of union. The freight car bolster spring is discussed in considerable detail, and suggestions offered for the possible elimination of it.

THE problems which confront the heat treater are utterly remote to most designers. It is true that the designer who has had a technical education in one of several universities, has been exposed to a brief training in metallurgy, but this seldom seems to take a permanent hold upon him. This statement is intended constructively. Our universities face a problem of the utmost complexity in their effort to train men to enter industry, and they are forced to compromise at every turn in order to crowd into the four years at their disposal the features which will give the young man the best all round preparation. Only as industry comes back to the universities with a clear picture of their needs, can industry logically expect those needs to be filled.

Perhaps the clearest way of bringing to the surface some of the foundation which the designer should have, from the heat treating standpoint, is to discuss at some length a specific problem of design. Almost any heat treated piece could be selected as the basis of this analysis, for example, the design and heat treatment of the large gears used in some electric locomotives present a problem for the closest possible co-operation between the designer and the metallurgist. The goal to be reached is a gear with a hard, strong structure which shall have a sufficiently true shape. The heat treatment may warp it out of plane, out of circularity, out of cylinder and it may be found to have undergone a variable

A paper presented before the ninth annual convention of the society held in Detroit, September 19 to 23, 1927. The author, G. M. Eaton, a member of the society, is associated with the Molybdenum Corporation of America, Pittsburgh. Manuscript received June 15, 1927.

permanent shrinkage. How can all these be prevented or at least brought closer to complete elimination?

Another attractive problem is found in the standard heat treated railway gear. If the bore is muffled during the quench, it is sometimes found after the bore is properly sized, by boring or grinding, that the press-fit allowance is not enough to give sufficient tonnage when pressing onto the axle. If this was always the case it would seem simple to give the reason, but it is only occasionally that this trouble is encountered. Let us look into this a little further. Neglecting martensitic dilatation in the first analysis, we find that when the gear is quenched with the axis vertical the most rapid cooling occurs in the teeth and in the immediately adjacent material, due to the existing ratio between thermal capacity and heat-dissipating surface. This causes the rim to contract and forge the underlying material, or in other words, plastic flow is produced in the material inside of the rim. This material is rather thin, but it is not readily accessible to convection currents and cools more slowly than would be expected judging solely from the ratio of thermal capacity to heat dissipating surface. The hub surrounding the bore is comparatively heavy and the bore is muffled, so that as the cooling progresses material plastic flow is produced in the hub. When the hub begins to equalize in temperature with the rim, the metal is too short circumferentially due to the plastic flow, and it proceeds to stretch. Much of this stretch must necessarily be of an elastic nature, and in the cases where the press tonnage is found to be too low, the internal hoop tension is close to the elastic limit. Therefore when the hoop stress of the press-fit is added to the internal stress, cold plastic flow occurs. But why does this not always happen? The only explanation that I can see is that by the combined action of a large number of small variables, different amounts of martensite are formed in the two cases. Where the press-fit is adequate the martensitic dilatation dissipates the hoop tension during the early stages of the quench and less plastic flow occurs in the underlying metal. But if the martensitic content falls below a certain amount the plastic flow takes place in a degree sufficient to cause the trouble. How can we tell by a quick, cheap commercial test the degree of hoop tension existing in the gear as it comes from the quench and temper?

On the other hand, if the bore is not muffled, the bore can be trued only by grinding. This is sometimes inconvenient for the customer, and several other questions are involved which are hardly germane to this discussion, as we only wish to show that the designer and heat treater must get together to secure the best possible solution of the railway gear problem.

Every heat treated product carries its own peculiar problems which will never be properly solved as long as the designer hands to the heat treater a definitely fixed shape of steel and requires of him that he produce certain specified physical characteristics. The two men must get together and each must carry his analysis clear into the field of the other, leaving no debatable ground between. Then and then only will our products assume the quality which we have a right to expect.

The product which we have selected for discussion in considerable detail is one which has confronted designers and heat treaters far longer than the gears to which reference has been made. This choice has been made because the problem is very active today, and no one is satisfied with the product. The service stresses are largely shear stresses, and the author's study of the product has led him to suspect that this particular type of shear service requires a radically different heat treatment than is required for bending service. (This will be discussed later.) We refer to heavy helical springs, where it seems essential to crowd the maximum carrying capacity into a minimum space. This is probably best illustrated by the freight car bolster spring.

There is much literature on the theory of helical spring design, and their detail performance under load can be determined with very great accuracy, but after a while they break. We can proceed to calculate by hand book formulae the stresses imposed, and we can conduct elaborate research tests to determine the endurance limit under torsion, and we arrive at the conclusion that theoretically they should not break. This means one or both of two things, either the theory is wrong or it is incomplete. I am going to try to show you that among other shortcomings the theory is incomplete, in that it has been based upon the assumption that steel is a perfectly uniform material. Our analysis as given here is only a start, and the heat treater's assistance is necessary, as we lack the knowledge required to complete the work.

We will define heat treatment as covering all heat cycles to which steel is subjected, from the ore to the finished product. We may not deal with all these cycles but we wish to avoid the interpretation that heat treatment deals only with heating, quenching and tempering operations.

If helical springs fail to perform as laboratory tests indicate that they should, it is logical to conclude that we have done something to the steel that is harmful, in making the spring, or else we fail to understand the conditions under which it is used. We will assume that the steel in the round rod is commercially good because tests made from these straight rounds show the results we have learned to expect.

The heating of the rods for coiling is a standard operation which is commercially successful for other purposes and if carefully done should be satisfactory for helical springs. Therefore it seems logical to focus our attention upon the coiling operation as the first place where we are justified in suspecting trouble.

TYPICAL FAILURE

If the steel is commercially sound, it will be found on inspecting one thousand helical springs which have broken under variable compression loading, that certain characteristics are in evidence in every single fracture, except of course where the evidence has been destroyed.

1. The failure will be found to have started at or near the inside diameter of the spring coil.
2. There will be a small well defined nucleus of failure, from which a fatigue crack progresses.
3. The fatigue crack will progress in a roughly semicircular shape.
4. The fatigue crack will follow the familiar diagonal direction of shear failure.
5. The direction of the slope of the fatigue crack will be the same as the direction of the slope of the spring coil, as shown in Fig. 1.

In addition to these characteristics which are absolutely common to all of the failures of helical springs loaded under varying compression, there are other features of the fractured surface which are in evidence in the overwhelming majority of cases.

1. The surface of the fatigued region is usually rippled or stepped instead of being of a smooth contour, see A, Fig. 1 and also Fig. 2.
2. There may be one, two, three or more of these steps.

3. These steps or ripples are most prominent near the surface of the wire and tend to die out as the crack progresses toward the center of the wire, and the later growth of the crack often follows a smooth contour.

4. Occasionally there is clear evidence to more than one small detailed fracture at first progressing independently and then more or less synchronously and gradually running together into a single fatigue crack.

5. Where a ripple or step appears in the fatigue surface, a thorough inspection shows that it meets the surface of the wire at

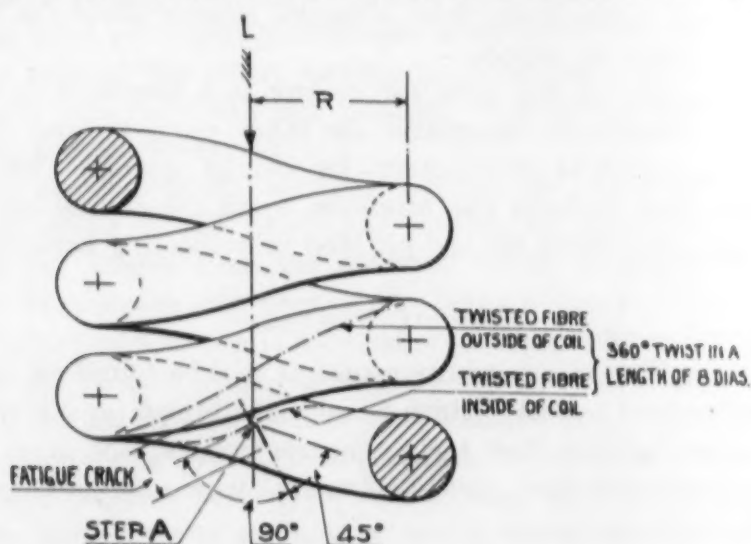


Fig 1—Showing the Slope of the Fatigue Crack to Be the Same as the Slope of the Spring Coil.

exact nucleus of failure. As a corollary of this fact where there is more than one well defined step, it can usually be shown that there is an independent nucleus of failure for each step.

In this connection the writer recommends urgently that those who are interested in working on this problem, make a prolonged study of the actual spring surfaces after failure. When the failure is clean and fresh, there is a wealth of information to be gained from a persistent analysis. You will find after spending a whole day on a single piece, that the second day will bring out evidence and history which was entirely overlooked during the first day. No ordinary photographer can do justice to the actual steel, but possibly macro photographs can be employed to advantage.

CAUSES OF FAILURE

It is perfectly obvious that there must be good reasons for the failure following the uniform type described. The first move is logically the investigation of the stress distribution in the spring

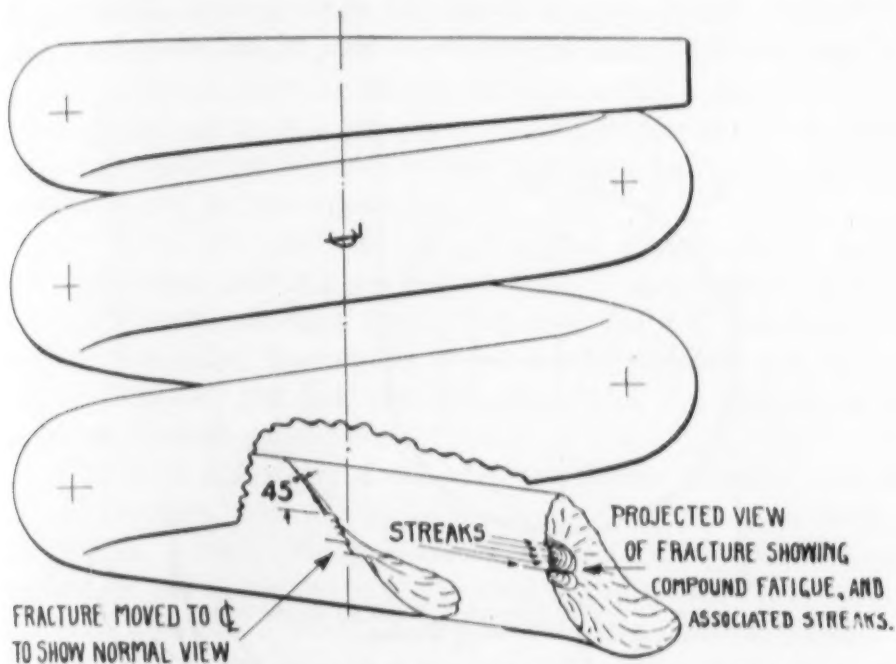


Fig. 2—Showing the Fatigued Region to be Rippled or Stepped.

to find out whether or not there is a stress concentration in the region where the failures localize.

We will let Fig. 3 represent any section through a free coil of the spring. This section of the spring supports the entire imposed load, L , Fig. 1, and without going into an elaborate discussion of shear distribution we may state that it is subject to a uniformly distributed direct shear across the diameter of the wire. See arrows S_d of Fig. 3. But this section of the wire is also subjected to torsional shear which is equal to the twisting moment divided by the resistance of the section to twisting. See arrows S_t of Fig. 3.

It is clear that the resultant shear on the inside of the coil is the cumulative effect of the direct and torsional shears, while on the outside of the coil the resultant is the differential effect of the two classes of shear. Without going into detailed calculations,

you will realize that this amounts to something when it is stated that in a case recently analyzed by the writer, the resultant stress on the inside of the coil was over 30 per cent higher than on the outside. (There is a further concentration of a more obscure nature which adds another increment of stress concentration in the same region and of about the same order.) This was in a class of service using thousands of tons of helical springs annual-

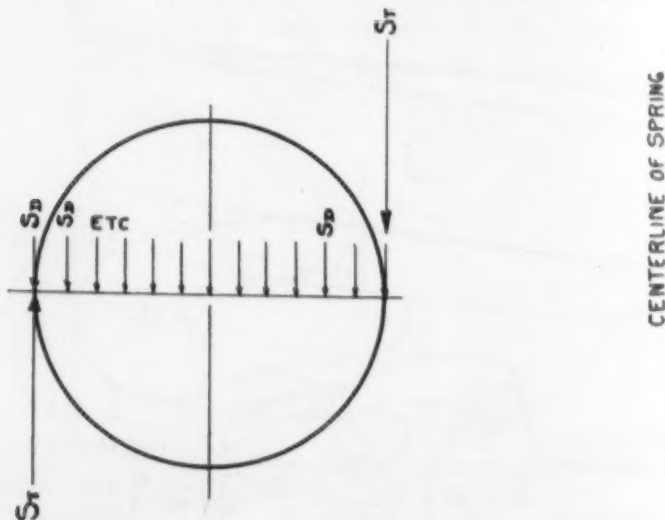


Fig. 3—Section Through a Free Coil of the Spring. Arrows Showing Direction of Shearing Stresses.

ly. It is only fair to note in passing that no formula which neglects these considerations is safe for universal application in spring design.

This is by no means a complete analysis of the stress distribution, but it is sufficient for our present purpose, which is to show that if we can produce springs which in the finished article have perfectly uniform material, we must still expect failure to occur at the inside of the coil if the spring is worked too hard.

Apparently then all that we can hope to do is to protect the critical region of the spring from all avoidable stress during the operations of manufacture.

Going a little further into the characteristics of failure which are of universal application, the diagonal characteristic is fully explained in text books¹ on the subject. However no reference is so prevalent that we should not neglect it, and there must be a reason.

¹Merriman's Mechanics of Materials.

We will now bring out a further characteristic tendency in the surface of the crack, which we omitted above because we wish to make it as prominent as possible. If we select a fracture which has only one step and where the entire surface shows a clean progressive crack (that is no tearing of the surface within the fatigued region), we will find on looking radially toward the axis of the wire, that what we may term the riser of the step is closely parallel with the axis of the wire. This looks like a small point, but in reality it is the key to the entire situation, when considered in combination with the fact that the step lies on the exact nucleus of the fatigue crack.

We have discussed in the preceding paragraph, a special case and before offering an explanation it is necessary to state that after having realized from your own study of failed springs that the preceding paragraph gives a true picture, you will be able to trace out the fact that the tendencies are present in the more complicated cases.

Why does the riser of the step lie closely parallel with the axis of the wire, and why does it also lie at the exact nucleus of the fatigue crack? We are forced to the conclusion that non-uniformity of the structure of the steel is the cause. This leads to the next question. What is the outstanding non-uniformity of the structure of the steel in a spring wire? Premature failures in heavy helical springs are the direct result of streaks in the steel, in the great majority of cases.

A broken spring made from steel that is absolutely free from streaks will show a fatigue crack without a ripple, and will be a spring that was hard to break, as compared with a like spring where streaks did exist.

We have now arrived at the point where it is logical to return to the act of coiling the spring and analyze as intimately as we may the tendency of this operation to inflict avoidable stress on the critical region of the spring. In this analysis we must keep uppermost in our minds the fact that the structure contains streaks which are weaker than the adjacent material, and we must avoid imposing on these streaks any avoidable forces tending to still further develop their weakness. The steel is at forging temperature, and is therefore in a condition where plastic phenomena are more prominent than those of an elastic nature.

The writer has made fairly extensive tests of a research nature in the attempt to gain a clear conception of the effect of coiling on streaks in plastic material. If we take a lead wire as a test piece, and make a narrow incision parallel to the axis to represent a streak, and then bend the wire into an arc of a circle, of a radius proportional to current practice in heavy helical springs, and with the incision on the inside of the bend, we can see the incision shorten and open. It is not necessary to enlarge on the seriousness of the most minute crack in steel that is to be heat treated. This test does not necessarily mean that a streak in a steel wire will open during the act of coiling. But it does mean that the tendency is present. If we now repeat the experiment with a piece of a solid rubber bicycle tire, we will find no tendency for the streak to open. This is because we are no longer dealing with a plastic material. If we repeat the experiment with the lead wire except that we place the incision on the outside of the coil we will see the incision lengthen and close.

Thus we have found in the critical region strong indication of a damaging tendency in the coiling operation as now carried out. We now face the question of how we can relieve the critical region from this tendency. Let us look at Fig. 1, and satisfy ourselves where we would like to place such streaks as we must accept, relative to the fatigue crack which we are now accepting.

It is perfectly obvious that the best position would be at right angles to the direction in which the fatigue crack occurs. In this relation we have reduced to a minimum the tendency for the streak to develop into a crack. It is also clear that this can be done very simply, by twisting the wire to the proper angle and direction, before the spring is coiled. This operation of course must be performed at forging temperature, and again we are in the field of plastic phenomena.

Restoring again to lead wire we find that if we make one twist of 360 degrees in a length equal to eight or ten times the diameter of the wire, our incision is positively closed and furthermore will remain closed during coiling. We also find that the incision lies practically at right angles to the direction of the fatigue crack in the coiled spring.

Referring further to the heat treatment of steel for torsional and direct shear service, in heavy helical springs, let us recapitulate

very briefly the mechanical features which should be given due consideration by the heat treater in evolving the heat treatment which constitutes the best possible compromise.

First. Heavy helical springs fail to perform in the manner that standard test pieces from the wire would lead us to expect.

This is notably outstanding in the case of alloy steels. Every step of the processes of production is therefore logically under fire, and we are thus justified in questioning the heat treatment.

Second. Failure always starts at the surface of the wire at or near the inside diameter of the coil. Therefore the heat treatment may be compromised in a measure if by so doing the condition of the critical surface can be improved. It may be possible to delay failure by sacrificing the quality of the structure at less strained regions for the sake of a more resistant critical surface.

This thought is advanced because it has been the author's experience that, to a considerable degree, the metallurgist forms his opinion of the adequacy of a steel for a spring by examining the fractured surface. If the fracture is sufficiently fine grained and of the proper texture to indicate a strong tough structure, the steel is considered good. The failure, however, does not start in the body of this structure, and I urge careful reconsideration of the whole heat treating problem to evolve a character of inspection of the steel that will determine the quality of the material which is going to fail first.

Third. (Intimately involved with the second feature.) Premature failures in heavy helical springs are very often the direct result of streaks in the steel. The heat treatment, therefore, should be built around the central idea of avoiding to the limit of possibility all force cycles during the treatment, which tend to start the development of nuclei of failure in streaks lying in the critical region. During the development stage it would be entirely logical to carry the compromise so far that failures have their nuclei within the body of the wire or at the outermost fibers of the coil. The ideal condition would probably be secured if the failures were indiscriminately distributed over the entire cross section of the wire.

The first approach to the analysis of this problem naturally follows the line of reasoning of Dr. Samuel L. Hoyt.² It would

²Stresses in Quenched and Tempered Steel, see TRANSACTIONS, American Society for Steel Treating, April, 1927.

seem at first glance that the ideal treatment would produce martensite in the surface in just sufficient degree to permit dilatation to compensate for shrinkage. I am not going to attempt to follow this through to a conclusion, because the line of thought is too new to me. It seems logical to consider that the mechanical set up has been brought with sufficient clearness into the territory of the heat treater, and that it is his proper function to carry on from this point.

Now there occurs a very vital departure from the fundamental basis on which Dr. Hoyt's work was predicated. He was working on a straight bar, in which all points of the surface were equally important. This is not true of the heavy helical spring. We have seen that our interest must center on a very restricted portion of the surface of the wire, viz., on the surface at and immediately adjacent to the inside diameter of the coil.

Until comparatively recent years, it was practically universal practice to quench heavy helical springs in still oil. With the spacing between coils usual in heavy freight car bolster springs, there was insufficient clearance between adjacent coils to allow free circulation of the oil by convection currents. This resulted in a spring where the inside fibers which were most strained in service had a lower elastic limit than the outer fibers which were subject to much lower strain.

This may be improved by force circulation of the quenching oil, and it is now possible to secure very uniform characteristics over the entire surface of the wire in the finished spring.

But apparently material further improved may be secured. If a quench can be developed where plastic flow and resulting internal stress cycles can be arranged so that the unavoidable damaging effects will be imposed on the fibers least stressed in service, we will capitalize on the fundamentally unbalanced working stress distribution over the cross section of the wire and will approach closer to the ideal spring.

If the central thought of our analysis somewhat approximates actual conditions, the seed of premature failure of heavy helical springs is now planted during the existence of hoop tension in the wire in the early stages of the quench. But if we focus the quench on the inside of the coil we gain a measure of protection against hoop tension over the critical region because in a direction tangential relative to the wire, plastic flow over the hot outer

part of the coil will tend to remove the reactive forces necessary for the establishment of hoop tension at the critical region.

The structure of the wire on the outside of the coil will be inferior at the completion of the heat treatment, but this is permissible if not carried too far and if it results in a structure in the critical region which is superior in the small details which now cause premature failure.

Again the author can only start the analysis, and arrives shortly at a point where the heat treater must carry on the work if it is to be done.

Quenching from the inside apparently means the use of a liquid or air spray head. There must be rotation of either the head or of the spring. The latter appears to be more fundamentally sound, with a liquid quench, because there is less danger of localized quench due to local spill of the liquid over the outside of the coils. The rotation should be established before the spray starts in order to eliminate sustained local impingement as far as possible.

The rotation should probably be as rapid as possible within the limit set by centrifugal force, which must not produce in the wire stresses in excess of the elastic limit of the hot steel. In an air hardening steel it is entirely possible that an air blast head could replace the spray head. There are also possibilities of using gases other than air though this looks rather far fetched. Steam quenching offers interesting possibilities.

From inherent thermal characteristics hydrogen would make a good medium, but the danger of explosion eliminates this. With a gas quench it appears better to hold the spring stationary and revolve the head for reasons brought out later.

Whatever the quenching medium there are certain obvious actions which will occur. As the innermost longitudinal fibers and the adjacent fibers of the coil start to cool they also start to shrink. From the standpoint of damage due to streaks in the surface of the wire this is the least dangerous shrinkage that can occur since it is parallel with the streaks. This shrinkage of the inner fibers tends to reduce the diameter of the coils, i. e., it tends to wind the spring to a smaller mandrel diameter. The first effect, however, will be a stretching of the inner fibers plastically until a point is reached where sufficient force is built up in the inner

metal, which is cooling and taking on a higher elastic limit to produce plastic elongation of the outer portion of the coil and other complicated plastic actions.

Thus far we have dealt only with a small part of the axial plastic flow which occurs in the early stages of the quench. A very complicated distribution of axial plastic flow will occur on the various elements of the surface of the wire. The important point is that by the internal quench we have, as previously stated, strengthened the critical region of the coil first, and we have accomplished this with a reduction of the hoop tension tending to open existing streaks in this region, while they are in a weakened condition due to high temperature.

You will, of course, realize that without dealing with phenomena of dilatation the designer is lost in a mass of complication, we will however follow it as far as we can with both the air and liquid quench.

If an air quench is employed, with the spring rotating, the blast must evidently be started very quickly after rotation is initiated on account of the quenching action set up on the outside by the act of rotation. Also the intensity of the blast on the inside of the coils must be sufficient to greatly exceed in its effect the rotational quenching action. Therefore, as previously stated, the spring should probably be stationary and the head should be in the form of a fan driven by the air blast.

Air quenching may be thought to eliminate the complication of local spilling of a liquid spray, but turbulence of the air must be suspected of tending to produce some degree of localization. However, it seems logical to believe that localization resulting from air turbulence will be less sharp than those associated with liquid spilling, as will be seen from the following more detailed analysis.

Let us assume that the line AA of Fig. 4 is an element of a cylinder having its axis coincident with the axis BB of a helical spring. Over this entire cylindrical surface there exists a uniformly distributed and radially outward air blast. We recognize fully that the establishment of this condition is accomplished by very grave difficulties. Before attempting their solution let us see whether with these difficulties solved we can secure the protection we seek, for the critical region of the spring. Fig. 4 shows the stream lines of an air quench somewhat as they would exist.

We find a small area C at the most critical region of the coil, where we will fail to secure the maximum rate of cooling. As we depart from C along the surface of the wire we reach a point D where the cooling rate attains a maximum. We do not know just where this point is, the location of the figure being hypothetical. Beyond D the cooling rate falls off and dies down to a

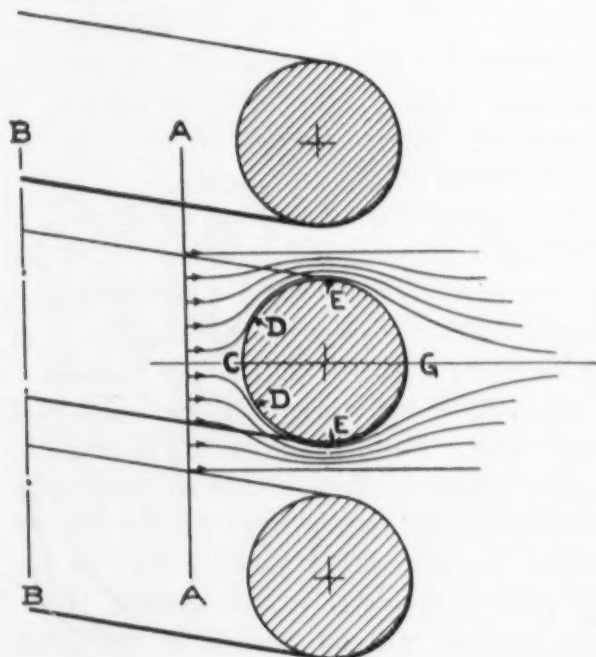


Fig. 4—Stream Lines of the Air Quench as They Would Exist.

very small value on the outside of the coil. The functions upon which all quantitative values of cooling gradient depend are too involved to be followed intelligently. It is clear however, that the relatively large zone of turbulence outside of the coil will be helpful in that it will retard the cooling effect in this region.

Up to this point we have neglected the rotational movement which is a necessity with any internal quench. There will be a certain amount of scrubbing effect over the area C as a result of rotation, and with the proper relation between the tangential and radial velocities of the air it may be possible to make a material reduction in the cooling lag at C.

The most doubtful features of an air quench are the possibility of securing axial uniformity of air distribution, and the further difficulty of securing a sufficient volume of air to produce the

speed of cooling that will be desired.

The great thermal capacity of the liquid quench constitutes a valuable fundamental advantage. The volume of quenching liquid is very small compared with the necessary volume of quenching air. Satisfactory quenching with air is dependent on high air velocity throughout the system, while satisfactory quenching with a liquid spray can be secured by means of pressure with negligible velocity up to the point of emission from the spray openings. The difficulty of securing uniform axial air distribution is a direct function of the axial velocity of the air. Therefore with a liquid quench we have disposed of both the volumetric and distribution difficulties of the air quench.

We will again assume axial uniformity of spray directed radially outward, at the surface of the cylinder AA of Fig. 4. We can approximate this pretty closely with a pressure system. We find that the general characteristics of the conditions at C are somewhat similar to those existing in the air quench. We will find less stream line effect, but there will be some cooling lag at C for a different reason. Even if the spring is rotated about its own axis at a speed producing stresses due to centrifugal force which are just safely below the elastic limit of the hot steel, it is quite doubtful whether the quenching medium will be thrown off until it reaches the outside diameter of the spring. But if we assume that the entire surface will be washed by the quench, there are still ways to cool the inside more rapidly than the outside. We can use a small volume of quench travelling at high velocity. The high velocity will bring the quench into very intimate contact with the hot metal at the point of impingement. This will decrease the resistance of the surface to the transfer of heat from the metal to the quench, so that the temperature of the quench will rise rapidly. Then when the quench reaches the outer surface it will abstract heat from it much less rapidly than from the inner surface, both because of the decreased temperature differential and because of the less intimate contact between the quench and the metal. With a low volume high velocity oil quench we must at once recognize a fire hazard.

Hot water offers interesting possibilities.

The first splash of the quench will be most effective at C because this is a normal impingement. But this first splash cannot

readily escape with its burden of heat, unless the quench has an evaporative characteristic, and there will probably be some accumulation of liquid at C, which will dilute the local quench and interfere with the effectiveness of subsequent impingement. Passing outward along the surface of the wire we reach a point D where the spray impinges and flows freely outward, producing a maximum cooling effect. Going still further outward the cooling effect dies down. We see here again arguments in favor of a careful investigation of the merits of a hot water quench. We are unable to evaluate the distance between the area C and the region D in either the air or liquid quench systems and therefore we cannot comment intelligently on the ratio of the distances CD in the two systems. With the liquid quench we have two real advantages. We are on more familiar ground and we have available for experimental work a far greater variety of steels.

Comparing the air and liquid quench systems, we find that the air quench involves more difficulties, that there are doubtful features that are about common to both systems and that there are definite advantages resident in the liquid quench. It is therefore evident that the sensible course is to exhaust the possibilities of the liquid quench before attempting the air quench. We must then start on an analysis of the force cycle attendant upon the liquid quench, pursuing it till we arrive at the region of impracticable complexity.

Fig. 5 shows the rigid ring which we shrink down onto the hot core of the spring wire with our present method of quenching. This we suspect of being the worst feature of the present quench and a feature which contributes directly to premature failure.

Fig. 6 shows the ideal structure which we hoped to achieve with an internal quench, and which we have failed to realize in full measure, but which we may possibly approximate with hot water. Fig. 7 shows the structure which we believe we can produce with a liquid internal quench. The stress visited upon the region C is a direct function of the distance CD. This is not the sole function but it appears to play an important part. We must now face the question—Is it worth while to try out an internal liquid quench?

In the judgment of the author there is sufficient probability of securing plastic flow tangentially relative to the perimeter of

the wire in parts outside the mean diameter of the coils, with this quench and which can by no possibility occur in the present quench except in company with a crack, to justify experimental work followed by tests to destruction to prove the value of the results.

The author regards the discussion of the effects of the internal quench as probably more plausible than logical but as stated, there seems to be sufficient ground for hope of improvement to justify experimentation.

The complete protection of the critical region from hoop stress may be approached by the reduction of heat gradient in the

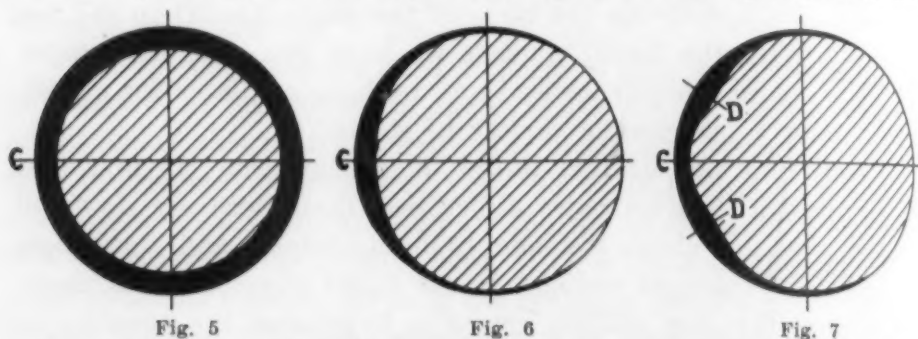


Fig. 5—Results of the Present Method of Quenching. Fig. 6—The Ideal Structure to be Attained. Fig. 7—Structure Believed to be Obtainable with an Internal Liquid Quench.

wire. But how can we secure the required strength without a sharp heat gradient? There is one possibility that probably deserves mention, though at the time of writing little is definitely known about what may be logically expected. We refer to a spring made from a molybdenum steel, twisted before coiling and then nitrogenized.

The critical surface will be hard and strong and there is some evidence leading us to hope the skin will exhibit considerable toughness. There will be no steep heat gradient in the process. But it is too early in this development to predict whether the core can be made strong enough without heat treatment. Perhaps heat treatment after twisting and before coiling will give the necessary characteristic. Furthermore we do not know whether the case will spall in service.

The point to be made is that when the designer makes a sincere attempt to analyze the problem presented by an apparently simple heat treated product he runs up against obstacles for the overcoming of which his training and experience have failed

to equip him, and his mind and the mind of the heat treater or metallurgical engineer must meet on a plane of mutual understanding.

Let us avoid the mistake of permitting an interesting problem to pry our attention away permanently from the major consideration which faces us. Why the gap between the metallurgist and the mechanical engineer? Why was the writer guilty of designing helical springs for over thirty years, and calmly watching them fail in service without turning a hand to attack the problem from the heat treating standpoint? Let us repeat here that we are not at all satisfied with the analysis of the helical spring problem to date and we see ahead a very great amount of work that must be done before helical springs are as good as we can make them with existing knowledge properly applied. How can the two professions get together to close the gap that now yawns between them?

The A. S. S. T. focuses the metallurgical and heat treating ability of the country. The A. S. M. E. bears the same relation to the mechanical designing brains of the country.

The problem of starting something of a constructive nature that will gradually evolve itself into the easing of our difficulties is something of the greatest complication and difficulty. It involves patient cooperation with our educational institutions in their difficult problem. It involves clear vision of the needs of industry and the establishment of intelligent research, and it involves sticking to it until the results come through.

I offer for your serious consideration and discussion the suggestion that a joint body be appointed by the two societies, and that on this body be laid the duty of tackling the job of bridging the gap between the art of the heat treater and that of the designer.

DISCUSSION

Written Discussion: By J. W. Rockefeller, Jr., representative of the American Society for Steel Treating on the A. S. M. E. special research committee on mechanical springs.

Mr. Eaton's paper has indeed revealed an important consideration too often neglected in research work; namely, the relation of the work done by an individual or group to the work done by others upon the same item in different stages of its production or use.

That Mr. Eaton has proved so conclusively the necessity of co-operative action on the part of the metallurgist with the mechanical engineer in research work upon springs is commendable.

The gap between the steel treater and the designer is one that must be bridged. Unfortunately if the results of such research are to escape unfavorable criticism from the steel maker, the automotive engineer and others interested, there are more gaps to be spanned; gaps that may assume the aspect of canyons depending upon the view point and occupation of the individual who is essaying to fit the fruits of the research to his particular needs.

It will be gratifying to Mr. Eaton to learn that the suggestion offered at the conclusion of his paper is one which has been incorporated already in the Special Research Committee on Mechanical Springs. When this committee was formed, a request to join in the research was sent to the American Society for Testing Materials, and the Society of Automotive Engineers in addition to the American Society for Steel Treating. All three of these societies replied that they would be pleased to have representatives serve on this committee and appointed them at once.

At a meeting of the Research Committee in New York City on December 9, 1926, these representatives after conferring with the executive officers in their several societies submitted reports on all work already completed, under way, and planned by their respective societies, as well as problems suggested for the main research committee. Copies of these reports are enclosed herewith.

The research of the special research committee on mechanical springs is guided by the periodic reports of the several societies represented, and in this manner attempts to cover every phase of spring design, manufacture, heat treatment and use. That part of the program dealing with the heat treatment, as well as the relation between heat treatment and design, must be outlined and accomplished by the American Society for Steel Treating. The application of springs to automotive work must be planned and executed by the Society of Automotive Engineers. The determination of suitable tests for spring materials becomes the problem of the American Society for Testing Materials. With all these organizations working together at the solution of their common and peculiar problems it is hoped that the gap mentioned in Mr. Eaton's paper as well as several others may be successfully spanned.

Written Discussion: By W. J. Merten, metallurgical engineer, Westinghouse Electric and Manufacturing Co.

There are several phases to this paper of considerable interest which have been presented exceptionally well. One is an ingenious analysis of stress distribution and direction in heat treated parts such as gears and springs. Also quenching stresses and strains, their significance and contribution to failure and effect upon service performance. Another is the judicious relocation of surface imperfections and defects in springs to render them harmless when applied in service. I have examined springs made of twisted seamy bars after a life test, or tested to destruction and had to admit that failure when occurred was not due to seams or surface imperfection, but to unsatis-

1927

factory or coarse granular structure from overheating for quenching, in fact, the fracture was some distance away from the seam, indicating that twisting the bar and directional adjustment of seams prevented concentration of stress there and the starting and progressing of a fracture at the bottom of the seam.

It certainly did not appeal to me from a standpoint of a user of springs and steel bars, to even consider the application or use of springs which, on surface inspection, showed seams and were considered defective. However, when one is shown by actual service tests that such spring, when manufactured under special conditions, to render the seriousness of the defects materially unimportant, performs, satisfactorily, the advocate of a practice of this kind certainly appears to deserve attention.

Internal spraying and other selective quenching and hardening methods proposed by Mr. Eaton are rather questionable, and I cannot see how the partial or local development of the satisfactory structural condition of the steel could possibly be advantageous over a uniformly hard and satisfactory structure, which we have agreed to be of a troostitic character. Some experiments we made during our locomotive quill spring development, definitely indicated that a uniformly hard quenched spring tempered to the proper Brinell after quenching did give considerably better performance than one obtained of proper Brinell Hardness without tempering, yet again a spring quenched in cold oil to maximum Brinell and tempered for a longer time to bring it back to the lower Brinell, performed better than those which were quenched in warm oil and consequently of lower Brinell after the quench, requiring, therefore, less time and lower temperature for tempering to the correct Brinell, which results do not favor Mr. Eaton's findings.

G. M. EATON: I would like to say that in connection with the training of men, which I have asked you to think about, I am not talking specifically about training men to handle elaborate research programs, though I am heartily in favor of such programs. Make them as complete as you can. This work outlined by Mr. Rockefeller is most constructive. But I am talking about the man who is pouring out design, pouring it out every day for commercial production. I contend that unless this man knows more about what he is doing from a metallurgical standpoint, the heat treated product is going to lag behind what it ought to be. As long as you let him hand the design over to you and say, "Here, John, get this physical characteristic," whether it is possible or not, we are not going to get to first base. I want men better trained for commercial production of heat treated products.

Educational Section

These Articles Have Been Selected Primarily For Their Educational
And Informational Character As Distinguished From
Reports Of Investigations And Research

FACTS AND PRINCIPLES CONCERNING STEEL AND HEAT TREATMENT—Part XV¹

By H. B. KNOWLTON

Abstract

This article discusses molybdenum and the steels containing molybdenum. The following points are brought out. An iron containing molybdenum has been used to a limited extent for some centuries, but the development of molybdenum metal and molybdenum steels are of recent origin. Molybdenum as the principal element in high speed steel has not met with much favor, but low amounts of molybdenum in conjunction with other alloying elements has proved very valuable in steels for engineering construction. It is claimed that molybdenum steels are inherently fine-grained, that they have a wide quenching range and that they are not "temper brittle." It is also claimed that by proper heat treatment a high degree of toughness in proportion to strength may be developed. Hardening with relatively mild quenching, deep penetration of the hardening effect, good forging and machining properties are among the advantages claimed for the molybdenum steels. The properties and uses of specific types of chromium - molybdenum, nickel - molybdenum, and chromium-nickel-molybdenum steels, are discussed.

MOLYBDENUM STEELS

History of Molybdenum

MOLYBDENUM is usually considered as one of the most recent additions to the family of alloying elements which are

¹This is the fifteenth installment of this series of articles by H. B. Knowlton. The several installments which have already appeared in TRANSACTIONS are as follows: March, June and October, 1925; January, April, May, June, August, October, December, 1926; March, May, July, September, 1927.

The author, H. B. Knowlton, member of the Fort Wayne Group of the Society, is metallurgist of the Fort Wayne Works, International Harvester Company, Fort Wayne, Ind.

used in the production of special alloy steels. It is interesting to note, however, that Dr. Sargent¹ reports that the Germans learned that some famous Japanese swords made during the fourteenth century contained a certain per cent of molybdenum. Undoubtedly the molybdenum was present as an impurity unknown to the Japanese. Following this discovery the Germans are said to have imported Japanese iron in large quantities. So while the element molybdenum was not known prior to 1790, the superiority of the iron which is now known to have contained molybdenum was recognized about six hundred years ago.

Until recent years molybdenum was considered a rare element. Scientific investigation of the addition of molybdenum to steel began in this country about 1890. Most of the work with molybdenum steels has been done in the last quarter of a century. Comparatively early in the development of high speed steels, molybdenum was used as the principal alloying element. The effect of the molybdenum seemed to be about the same as tungsten except that less molybdenum was required to produce steels possessing "red hardness" (ability to stand reheating to a dull red heat after hardening and tempering without serious loss of hardness). However, these steels did not meet with much favor among the American metallurgists. It was reported that the molybdenum was volatilized from the surface of the steel during the forging operations. In recent years the high speed tool steels have contained tungsten rather than molybdenum.

The manufacture of the metal molybdenum itself is more recent even than its use in conjunction with iron. This was probably due in part to the fact that its high melting point (4757 degrees Fahr.) makes the metallurgy rather difficult. Like tungsten, it is not melted in the course of manufacture. Instead the ore is chemically purified into a metallic powder which is pressed into sticks and solidified by passing a heavy electric current through the sticks. The ingots thus formed are rolled or drawn to the required shapes. Pure molybdenum is a white metal somewhat similar to platinum. It is resistant to heat and most chemical actions. It is used principally as brackets in electric lamps and for certain parts of radio tubes.

Molybdenum is added to steel in the form of ferromolybdenum (an iron-molybdenum alloy) or in the form of a chemical compound

¹TRANSACTIONS, American Society for Steel Treating, Vol. 1, No. 10, 1921.

containing molybdenum. It is readily absorbed by the steel at the ordinary melting temperature.

Molybdenum steels have come into commercial prominence during and since the World War. German armor plate and some other ordnance parts contained a small amount of molybdenum in conjunction with other alloying elements. The commercial development of molybdenum steels in this country has been made possible by the discovery of large deposits of molybdenum within the boundaries of the United States.

EFFECT OF MOLYBDENUM IN STEEL

Molybdenum forms a solid solution with iron and complex compounds with iron and carbon. It is said to inhibit grain growth when steel is heated to high temperatures. Thus a wider range of temperatures may be employed in heating for forging and hardening. Molybdenum, like most of the other alloying elements which combine with carbon, raises the critical point on heating. In order to completely dissolve molybdenum carbides it is necessary to heat to higher temperatures than those required to bring about solution of iron carbide in the corresponding plain carbon steels. However, as molybdenum inhibits grain growth the use of higher temperatures does not produce a coarse grain. Once the carbides are in solution they do not separate out as readily in a molybdenum steel as they do in a similar plain carbon steel. In tempering molybdenum steels after quenching it is common to hold them at the tempering temperature for a comparatively long time. Molybdenum is said to intensify the action of heat treatment and develop higher physical properties than obtained in a corresponding steel without molybdenum. Unlike some of the other alloying elements, molybdenum does not have a greater affinity for oxygen than the other elements in the melted steel. Consequently molybdenum does not act as a deoxidizer in the manufacture of steel. It is claimed for the steels containing molybdenum that they are less susceptible to "temper brittleness" than are some of the other alloy steels. Good forging and machining properties are also claimed. Some of these points will be discussed more fully later.

Fig. 1 shows the constitutional diagram for the carbon-molybdenum steels. It will be noted that this diagram is divided into two fields, the cementitic and the pearlitic. Thus steels which have high molybdenum contents are cementitic after cooling slowly

1927

from above the critical point, while the low molybdenum steels have a pearlitic structure after slow cooling.

The old type of high speed steel previously mentioned fell in the cementitic zone. It was similar in structure to the more common tungsten high speed steels. The high molybdenum type of high speed steel is not in common usage. However, molybdenum in

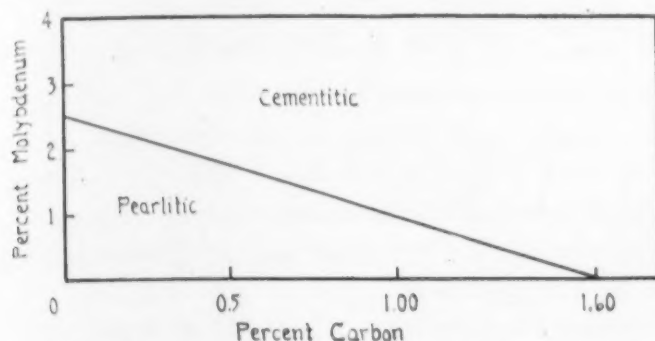


Fig. 1—Molybdenum Steel. Constitutional Diagram (Guillet).

amounts up to 2 per cent is used in conjunction with other alloying elements in various types of tool steels. Those containing high alloy contents are cementitic while those with lower alloy contents are pearlitic.

From the commercial standpoint the most important molybdenum steels are those which contain less than 1 per cent of molybdenum. Such steels are pearlitic after slow cooling from above the critical point. They are subject to the same annealing, hardening and tempering treatments as the other pearlitic plain carbon and alloy steels. While there may be some uses for steels containing molybdenum as the only alloying element, molybdenum is usually employed with some other alloying element such as chromium, nickel or vanadium or combinations of these elements.

CHROMIUM-MOLYBDENUM STEELS

The best known of the chromium-molybdenum steels are the two given by the S. A. E. Handbook. These are designated as S. A. E. 4130 and 4140. The limits for chemical analysis specified are:

	S. A. E. 4130	S. A. E. 4140
	Per Cent	Per Cent
Carbon.....	0.25-0.35	0.35-0.45
Manganese.....	0.40-0.70	0.40-0.70
Phosphorus.....	0.040 Max	0.04 Max

Sulphur.....	0.045 Max	0.045 Max
Chromium.....	0.50-0.80	0.80-1.10
Molybdenum.....	0.15-0.25	0.15-0.25

It will be noted that the molybdenum content is the same for both steels and is very low. The specifications for the two steels are identical except that the 4140 averages 10 points higher in carbon and 30 points higher in chromium.

S. A. E. 4130 STEEL

This type of steel is used for heat treated parts such as steering knuckles, shafts and similar automotive parts. It is used interchangeably with 2330 (nickel steel) 3130 (low-chromium-nickel steel) and 6130 (chromium-vanadium steel). It may be quenched in water successfully. The following heat treatment is recommended by the A. S. S. T. Handbook.

Normalizing Temperature	1650-1750 degrees Fahr
Quenching Temperature	1550-1650 degrees Fahr.
Quenching Medium	Water
Tempering	as required—a long soak recommended

The physical properties produced by applying such treatments to 1¼ inch round specimens of this steel are shown by the curves in Fig. 2.

S. A. E. 4140 STEEL

This steel is similar to 4130 except for the higher carbon and chromium contents. It is listed as an oil quenching steel. The physical properties obtainable by heat treating this steel are slightly higher than those obtained by applying similar treatments to 4130. The following heat treatment is recommended by the A. S. S. T. and S. A. E. Handbooks.

Normalize at 1650-1750 degrees Fahr.
Reheat to 1525-1625 degrees Fahr.
Quench in oil
Tempering as required—a long soak recommended.

The S. A. E. further recommends the following heat treatments for parts which are to be heat treated after forging and before heat treating.

Normalize at 1650-1750 degrees Fahr.
Reheat to 1250-1350 degrees Fahr.
Cool slowly
Machine
Reheat to 1525-1625 degrees Fahr.
Quench in oil
Temper to required hardness.

The reheating to 1250-1350 degrees Fahr. after normalizing is recommended to increase the machinability, as the forgings may be rather hard after air cooling from normalizing. The physical properties obtained by heat treatment are shown by the curves in Fig. 3

S. A. E. 4150 STEEL

This steel is mentioned by the A. S. S. T. Handbook but not by the S. A. E. Handbook. Its composition is exactly the same as 4140

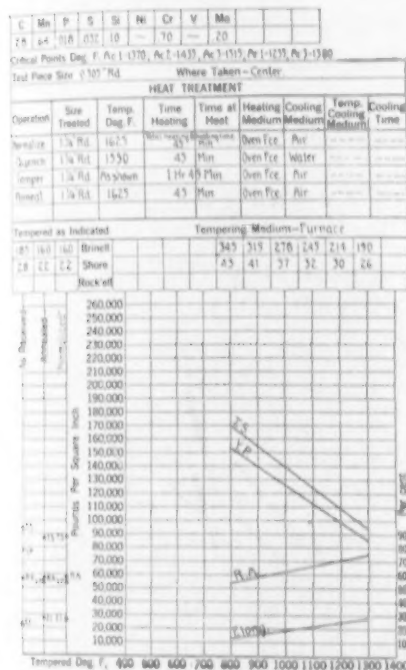


Fig. 2—Physical Property Chart for Chromium-Molybdenum Steel (S. A. E. 4130).

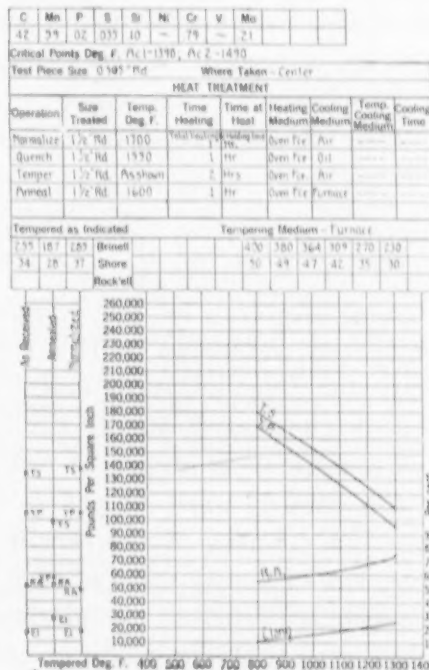


Fig. 3—Physical Property Chart for Chromium-Molybdenum Steel (S. A. E. 4140).

except that the average carbon content is 50 instead of 40, hence the term 4150. It is also an oil hardening steel and is designed for such parts as oil hardened gears, roller bearings etc. which must have the ability to resist wear as well as possess great toughness. It is also recommended for parts such as leaf springs which must withstand high stresses. The heat treatments are similar to those recommended for 4140 steel except that the quenching temperature may be slightly lower. For parts such as gears which require a high degree of hardness, lower tempering temperatures may be required.

OTHER CHROMIUM-MOLYBDENUM STEELS

The above mentioned steels are probably the most commonly used of the chromium-molybdenum family. However, reference to the literature put out by the Climax Molybdenum Co. shows that at times chromium-molybdenum steels of other compositions have been recommended. Molybdenum contents varying from 0.25-1.00 per cent have been tried. Higher values for tensile strength and yield point are claimed for steels containing higher molybdenum contents (up to 0.75 per cent). Low carbon-molybdenum steels have also been used for case hardened parts. At present nickel-molybdenum is more commonly recommended for this purpose.

ADVANTAGES CLAIMED FOR CHROMIUM-MOLYBDENUM STEELS

There can be no doubt that some very desirable combinations of physical properties can be obtained by heat treating chromium-molybdenum steels. In general the physical properties are similar to those produced by heat treating other medium carbon alloy steels previously described in this series of articles. One of the claims made for the chromium-molybdenum steels is that the reduction of area (measured during the tensile test) produced by any given heat treatment is higher in proportion to the tensile strength, than in the case of most of the alloy steels. The elongation and the reduction of area of the tensile test specimen are usually taken as measures of the toughness of a steel. In general when the tensile strength is increased the elongation and the reduction of area are decreased. It is obviously an advantage to have a steel possessing high tensile strength combined with high values of elongation and reduction as this means a combination of great strength and great toughness.

The relative emphasis which should be placed on each of the four values determined during the tensile test (that is the tensile strength, the yield point, the elongation and the reduction of area) may be a debatable question. Some metallurgists hold that the reduction of area is a better measure of plasticity and toughness than the elongation. Several years ago a mathematical formula called a "merit index" was proposed² for determining the relative merits of different steels. This formula expressed in words is as follows:

²I. D. Custer, TRANSACTIONS, American Society for Steel Treating, Vol. 1, No. 3, 1920.

$$\text{Merit Index} = \frac{\text{Mean Strength} \times \text{Elongation (\%)}}{100\% - \text{Reduction of Area (\%)}}$$

The "mean strength" in this formula is a figure half way between the yield point and the ultimate tensile strength. It was claimed that this formula is proportional to the amount of work done in breaking the specimen. Expressed in another way the merit index is the force exerted on the tensile specimen multiplied by the distance that the specimen elongates divided by the final cross sectional area. Assuming that this formula gives a true index of the relative merit of different materials, Dawe³ shows that the chromium-molybdenum steels have a higher merit index than the other common alloy steels of corresponding carbon contents.

On the other hand some engineers have challenged the validity of this formula as a true index of merit of different steels and other materials of construction. As the final cross sectional area (100 per cent reduction of area) is placed alone in the denominator of the fraction, a great deal of emphasis is placed on the reduction of area. For example let us consider a hypothetical case of a material which has a very low strength but which is so plastic that it can be stretched to 10 times its original length and be reduced to 1/100 its original diameter before breaking. Let us assume the following figures and compute the merit index.

Tensile strength 10 pounds per square inch
 Elastic limit or yield point 0 pounds per square inch
 Elongation 1000 per cent (10 times the original length)
 Reduction of area 99.99 per cent (Final diameter 1/100 of the original)

$$\text{Then the mean strength} = \frac{10+0}{2} = 5 \text{ pounds per square inch}$$

Substituting these figures in the formula

$$\text{Merit Index} = \frac{\text{Mean strength} \times \text{elongation}}{100 - \text{Reduction of area}}$$

we find that

$$\text{Merit Index} = \frac{5 \times 1000}{100 - 99.99} = \frac{5000}{.01} = 500,000$$

This is a very high figure compared with the merit indexes of steels which are below 100. Following the same line of reasoning a material like warm taffy with low strength but ability to stand

³Chromium-Molybdenum Steel Applications from the Consumer's Viewpoint, *Journal*, Society of Automotive Engineers, January, 1922.

much stretching and reduction in area would have a much higher merit than any steel. The fallacy of this assumption is too obvious to warrant discussion.

However, while the mathematical correctness of the formula given for the merit index may be challenged, it can not be disputed that a combination of high strength and a high degree of plasticity as shown by the elongation and the reduction of area, is very valuable in a material for engineering construction. It will probably not be disputed that if two steels possess the same strength and elastic limit, that the one with the highest elongation and reduction of area is the more valuable for most construction purposes. The high figures for the reduction of area of chromium-molybdenum steels can be claimed as an advantage.

QUENCHING RANGE

Another of the advantages claimed for the chromium-molybdenum steels is the wide range of quenching temperatures which may be used in heat treatment without greatly changing the physical properties produced. This is due to the fact that molybdenum tends to keep down grain growth and consequently over-heating does not produce serious results. It is sometimes stated that the chromium-molybdenum steels are more fool proof in the heat treating room than are some of the other steels.

PENETRATION OF HARDNESS

The chromium-molybdenum steels like some of the other alloy steels harden with a slower speed of cooling than plain carbon steels. Consequently the hardening effect of quenching penetrates deeper into the steel. It is often desirable that heat treated parts should have the same physical properties from surface to center. It is claimed that the chromium-molybdenum steels are very good in producing such uniformity of properties after heat treating. For example it is stated^{*} that Brinell readings made diagonally across the cross section of a $3\frac{1}{2}$ inch square bar of heat treated 0.30 per cent carbon chromium-molybdenum steel showed a Brinell hardness of 293 at the surface and 262 at the center. For this reason it is claimed that chromium-molybdenum steels are well adapted for large sections.

^{*}Molybdenum in Commercial Steels: Climax Molybdenum Co., 1919.

TEMPER BRITTLINESS

It has been found that some steels have a lower impact strength after slow cooling from tempering than after quenching from tempering. This phenomenon is called "temper brittleness." A steel which possesses the same strength after slow cooling and after quenching from tempering is said not to be susceptible to temper brittleness. Greaves and Jones⁵ state that chromium-molybdenum and nickel-chromium-molybdenum steels containing 0.3 per cent molybdenum showed no susceptibility to temper brittleness.

FORGING AND MACHINING PROPERTIES

It may be stated that in general steels with high tensile strength are more difficult to forge and machine than steels having low tensile strength. It is the object of every manufacturer of alloy steel to produce steels having as good forging and machining properties as possible in proportion to the tensile strength. The Climax Molybdenum Co. has published some data sheets setting forth the claims for their steels in this respect.

NICKEL-MOLYBDENUM STEEL

Within the past few years a nickel-molybdenum steel with a low carbon content has become quite popular in quarters for case hardening. This is described as S. A. E. 4615. The limits of chemical analysis specified are as follows.

	Per Cent
Carbon.....	0.10-0.20
Manganese.....	0.30-0.50
Sulphur.....	0.045 Max
Phosphorus.....	0.040 Max
Nickel.....	1.25-1.75
Molybdenum.....	0.20-0.30

The heat treatment practice recommended by the A. S. S. T. Handbook is as follows:

Carburizing Temperature	1600-1650 degrees Fahr.
Quenching Temperature	1475-1550 degrees Fahr.
Quenching Medium	Oil

One of the principal advantages claimed for this steel is that good properties of both case and core may be obtained by slow cooling from carburizing followed by reheating to about 1500 degrees Fahr. and quenching in oil. The single quench in oil from the

⁵Iron and Steel Institute (Great Britain), 1925, No. 1, Vol. CXI.

moderate temperature does not produce as much distortion as is commonly produced by double quenching treatments. With many steels it is necessary to give a high quench to refine the core, followed by a low quench to refine the case. Some metallurgists prefer to give all case hardening steels a double quenching treatment. However, single quenching is very desirable in the case of gears and other parts which must be held very accurately to size, providing good physical properties of case and core can be obtained with the single quench. With most steels a single high quench produces a strong core but a coarse grained case which is likely to spall. A single low quench just above the critical point for the case produces a fine grained hard case but a weak core. If the carbon content is above 1.00 per cent at the outside there will be a network structure of cementite in the case which may also cause spalling. With molybdenum present, it is claimed that a medium high quenching temperature such as 1500 degrees Fahr. may be used without much coarsening of the grain of the case. At the same time the core will be strengthened by the treatment. It is probably good advice when the single quenching treatment is to be used, to carburize at a comparatively low temperature (about 1600 degrees Fahr.) and thus avoid the high concentration of carbon at the surface and the consequent net work structure of excess cementite.

It is reported that a nickel-molybdenum steel with nickel and carbon contents a little higher than in 4615, was successfully used during the World War for armor plates of the famous tanks. These armor plates had to withstand a direct hit of "armor piercing" or explosive bullets without being pierced or badly cracked. The old armor plate used on American artillery vehicles had to withstand the impact of the regular infantry rifle bullet. The thickness of armor plates varied from $\frac{1}{4}$ to $\frac{5}{8}$ inches. Some of these plates had to be formed into rather intricate shapes. It required very exceptional properties to withstand the impact of the armor piercing bullets, but the nickel molybdenum steel plates passed the ballistic tests very well. While it is not possible to verify the statement at this date, it is the writer's memory that the analysis of some German light protective armor plate showed that they used a chromium-nickel-molybdenum steel.

CHROMIUM-NICKEL-MOLYBDENUM STEEL

While this type of steel is not as commonly used as the

chromium-molybdenum steels, it is worthy of mention since some very good physical properties have been developed with this steel. The pamphlet on "Molybdenum in Commercial Steels" published in 1919 gives the following table as the average values obtained by testing finished crank shafts of the liberty motor.

Chemical Analysis	
	Per Cent
Carbon	0.236-0.305
Manganese	0.50 -0.69
Silicon	0.08 -0.52
Chromium	0.74 -0.98
Nickel	2.85 -3.05
Molybdenum	0.32 -0.54

Physical Properties	
Yield Point	130,000 pounds per square inch
Ultimate Strength	142,000 pounds per square inch
Elongation	20.5 Per Cent
Reduction of Area	65.0 Per Cent
Izod (Impact)	67 Foot Pounds
Brinell Hardness	303

The treatment given was as follows:

Forged and twisted.

Normalized at 1600-1650 degrees Fahr. Cooled in air.

Reheated to 1475 degrees Fahr.

Quenched in water.

Tempered at 1150 degrees Fahr. for 2 hours.

Cooled in air and straightened before the temperature reached 800 degrees Fahr.

Chromium-nickel-molybdenum steels have also been used successfully for steel castings. One manufacturer of alloy steel castings has reported that nickel-chromium-molybdenum steel castings when cooled in air from above the upper critical point, develop as good physical properties as those produced in some other types of steel castings by quenching and tempering. The advantage of producing physical properties by air cooling instead of quenching is quite obvious, for there is always danger of setting up strains resulting in cracking or reduced strength, when castings are quenched, particularly if they are large or intricately designed. Furthermore air cooling is much cheaper than quenching and tempering.

Molybdenum is also used in conjunction with other alloying elements in the manufacture of large drop hammer die blocks. Some die blocks contain nickel, chromium, vanadium and molybdenum. The carbon content is about 0.55 per cent. Such

die blocks are sometimes used in the air cooled condition. Longer life can be attained by quenching in oil or water. Probably the best physical properties are produced by quenching face down in water with the shank remaining in the air. The quench is timed and the block is removed from the quenching bath while the center is still hot. It is sometimes then placed on a hot plate until the face becomes somewhat heated, and is then transferred to the tempering oven and is tempered to the desired hardness. All of these operations are performed before the center of the block becomes cold. The molybdenum in these blocks helps to produce a fine grain and increases the penetration of the hardness.

A CRITICAL STUDY OF THE BEND TEST AS APPLIED TO IRON AND STEEL

(Continued from Page 793)

ultimate stress is not used, but a figure obtained by dividing it by five, or three, or two, or whatever the factor of safety may be. In addition to that factor of safety, there is a factor of safety afforded by ductility, so that when a load is suddenly applied, the material can absorb it, and the total stress which results will not be so high.

In the same way the bend test comes in. That is, it is an extra insurance factor so far as structural design goes and holds the same general position as does elongation and reduction of area. Moreover, combined with a hardness test it gives a very good estimate of the properties of the material when the tensile test is not available.

Regarding Mr. Lessells' discussion, it is appreciated very much, and some of his points I thoroughly agree with. Regarding the failure at the center of the surface rather than at the edge, we only differ in nomenclature. I said that the reason failure occurred at the center was that the piece at that point was in two-dimensional stress, whereas at the edge it was in uni-dimensional stress.

Regarding the displacement of the neutral axis, I pointed out in the paper that it was displaced inwards. I disagree with Mr. Lessells that the stress is proportional to the distance from the neutral axis. In fact, I think Mr. Lessells himself, in his book on elasticity, states that the stress distribution is hyperbolic and not a straight line function. In that way, even though the point is not so far from the neutral axis, the stress is considerably increased.

Regarding Poisson's ratio and stress versus strain; this is an academic question. I have always thought of Poisson's ratio as the actual stress which causes the strain. Take your choice; it makes no difference in the reasoning. In the same way when we are above the elastic limit, in the plastic zone we have lateral forces.

Comment and Discussion

Papers and Articles Presented Before the Society and Published in Transactions Are Open to Comment and Discussion in This Column

DISCUSSION OF G. W. QUICK AND L. JORDAN'S PAPER ENTITLED "IRON-CARBON-VANADIUM ALLOY FOR BRINELL BALLS"

BY DR. AXEL HULTGREN*

THIS investigation has clearly proven that the error caused by the elastic flattening of the Brinell ball, when testing hardened steel, is considerable. This fact has been to some extent, if not wholly, overlooked by previous workers on Brinell testing, including the writer. The authors, although increasing the hardness of the balls, did not succeed in producing Brinell balls greatly superior to those already available but their results are most valuable—as negative results often are—in that they point out the way to further improvement. It is to be hoped that renewed efforts will be made, and successfully, to discover a ball material that will suffer no permanent, and negligible elastic flattening in the test, and that will stand repeated loading without rupture or appreciable wear.

Until such a material will be found, cold-worked steel balls should be of service, whenever the Brinell test on hardened steel is desirable. When used for material in the hardness range of, say, 500 to 700 Brinell, those balls give values that, although not correct, form a continuous scale of hardness with the Brinell numbers below 500 obtained with ordinary steel balls, owing to the fact that cold working does not alter the elastic modulus of steel.

As was pointed out in the verbal discussion, the Rockwell diamond cone hardness tester is a most valuable instrument, for some purposes more useful than the Brinell machine, but, like the latter in its application to hardened steel, it suffers from the shortcomings of the indenter. Judging from the difference in results that may be obtained when using different new cones on the same piece of steel, it has not as yet been possible to make the cones exactly alike. Furthermore, the point of the cone is liable to disintegrate on continued use, causing erroneous readings and necessitating frequent checking on the standard block. For such reasons the writer looks forward to the discovery of an indenter material of the qualities mentioned above as a means of improving the Rockwell method as well.

Going one step further, one may well conceive the possibility of a combination of these two related methods of hardness testing in the future, by using a superhard ball, measuring the depth of penetration

*TRANSACTIONS, American Society for Steel Treating, Vol. XI, page 62.

*The author of this discussion, Dr. Axel Hultgren of Soderfors, Sweden, is a member of the society. Manuscript of this discussion received September, 1927.

according to Rockwell and reading the Brinell number on the dial or obtaining it by a simple conversion.

The authors report, that they found considerable difficulty in measuring the diameter of impression even when etched balls were used. The present writer never experienced such difficulty and ventures to ask whether the illumination was arranged as suggested in his paper². In this connection he wishes to refer to a statement³ to the effect that etching of Brinell balls, suggested by the present writer in 1920, was already originated at the Bureau of Standards in 1915 or 1916. It would be of interest to have authoritative information on this point.

I wish to inform the authors that the special balls tested by Foss and Brumfield were cold-worked.

In the investigation mentioned by the authors the writer came to the conclusion that no increase in the hardness of cold-worked balls appeared to be effected by the use of alloy steel or by special heat-treatment. This conclusion was tentative as seen from the word "appear". Otherwise, I acknowledge being corrected on this point by the authors' work.

The micrographs of the vanadium alloy show, standing in relief, a great number of carbide particles, probably identical with the hard vanadium single carbide of vanadium-bearing high carbon steels and high speed steels. Possibly there is a connection between the great hardness and number of the carbide particles and the hardness of the heat treated alloy. From the composition of the alloy it may be inferred that most of the vanadium is probably absorbed by the carbide, leaving only a small amount in solution in the matrix to affect the properties of the latter. If that is true, it probably consists of martensite.

In conclusion I wish to congratulate the authors on their sound paper

AUTHORS' REPLY TO WRITTEN DISCUSSION BY DR. AXEL HULTGREN

Dr. Hultgren asks as to the method of illumination employed while reading the diameters of the ball impressions. The method described by Dr. Hultgren in the paper to which he refers was used for some of the readings but not for all. As to the comment on the ease with which the indentation diameters could be read with etched and polished balls, it is not to be inferred that the authors regarded the etching of the ball as of no advantage and the statement is simply that with either type of impression "considerable difficulty was experienced". Possibly a better phraseology would be that considerable care was required, in making precise readings of the diameter.

Dr. Hultgren also requests information relating to a statement concerning the development of the etched Brinell ball made by Mr. H. A. Holz in discussion of a paper by Mr. H. M. German. As far as we are able to ascertain from examination of files and also from the recollection of the members of the Bureau Staff concerned with Brinell testing at the period in question, the suggestion of the use of an etched Brinell ball came in

²*Journal, Iron and Steel Institute, Vol. II, page 204, 1924.*

1927

a written memorandum from Dr. Hultgren to the Committee on Hardness of the National Research Council. At the request of the Committee tests of etched balls were made at the Bureau of Standards and the report of those tests was included in the report of the Hardness Committee published in *Mechanical Engineering* for July, 1921, Vol. 43, No. 7, page 445. Credit for the suggestion for etching the balls is thus definitely due to Dr. Hultgren and not to the Bureau.

AN ERROR CORRECTED

The article on page 306 of the August, 1927, issue of *TRANSACTIONS*, entitled, "No Substitutes for Manganese in Steel," unfortunately contained several mis-statements which were not suspected by the editor on account of its origin at the Bureau of Mines. It appears, however, that the statement did not emanate from the Metallurgical Department of the Bureau, but instead from some other department. It has been called to our attention by metallurgists who are familiar with the facts in regard to the deoxidation of steel that the following corrections should be made:

(1) Ferrotitanium is not the most powerful deoxidizer known, although it is one of the strongest.

(2) Ferrotitanium is widely used in many high-grade as well as ordinary steels, and does not impart to them qualities that are not acceptable to the trade. If it did, it is obvious that the consumption of this alloy would have rapidly decreased long ago, instead of being maintained at a high monthly tonnage for years.

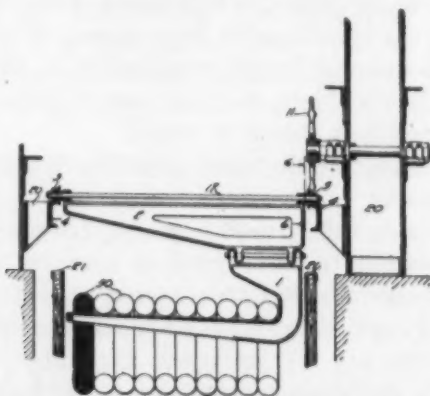
(3) Vanadium is used in many high-grade steels, and does not prevent the production of homogeneous steel.

Reviews of Recent Patents

By NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City—Member of A. S. S. T.

1,643,186, Machine for Pickling Coils of Wire or Rods, Horace A. Staples, of Plainfield, and Harold K. Beach, of Roselle, New Jersey, Assignors to American Copper Products Corp., of New York, a corporation of Delaware.

This patent describes a machine for pickling coils of wire or rod in which the coils 50 are suspended from the horizontal arms 1, supported



from the structure 2 for transmission along the tracks 4 by means of the rollers 3. In a passage over the pickling and washing baths, the arms 1 are given a horizontal as well as a vertical movement to permit them to immerse the coils 50 in the pickling tanks and remove them. At certain points in the movement of the coils through the acid baths, the arms are given a vertical vibratory motion to shake out the air and scale in the coils, facilitating the pickling and assuring a more uniform product.

1,643,054, Steel Alloy, Linwood M. Brown, of Pittsburgh.

This patent describes a steel alloy for the making of cutting tools which are characterized by increased strength and toughness with improved hardening qualities. The alloy preferably is of the following composition:

	Per Cent
Carbon	0.40 to 1.00
Manganese	0.50 to 1.50
Silicon	1.50 to 2.50
Molybdenum	0.15 to 1.50
Vanadium	0.15 to 0.50
Combined molybdenum and vanadium.....	0.50 to 1.00

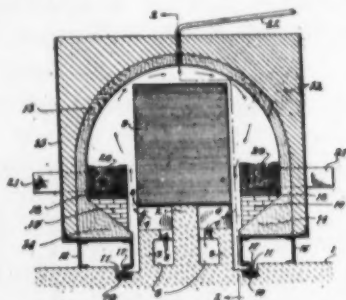
Phosphorus and sulphur should be less than 0.04 per cent and the iron content will be sufficient to make 100 per cent. The alloys of this composition

1927

have great resistance to crystallization or fatigue and are particularly adapted for use as rock drills and similar percussive tools.

1,643,600, Electric Annealing Hood, Thaddeus F. Bally, of Alliance, Ohio.

This patent describes an annealing hood consisting of a fixed pedestal 2, supporting a plate 8 upon which the sheets 9 or other articles to be annealed may be placed and a removable hood 12 adapted to be



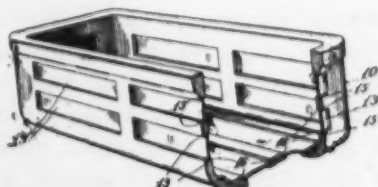
placed over the stack of sheets 9 and to co-operate with the sand seal 10 to effectively seal the interior of the hood. A granular resistance material 20 is contained in the trough 18 and electrodes 21 embedded in the resistance material to connect the resistance material to the current supply. Non-oxidizing atmosphere may be generated in the hood by passing oil through the pipe 22 and permitting the oil to drop on the top of the hot pack of sheets.

1,643,304, Silver-Silicon Alloy and Process of Making the Same, Michael G. Korsunsky, of Jackson Heights, New York, Now by Judicial Change of Name Michael George Corson, Assignor to Electro Metallurgical Co., a corporation of West Virginia.

This patent describes a silver-silicon alloy of improved wear-resisting qualities and substantial freedom from tarnishing as compared with the usual sterling silver. The silicon should preferably be present in amounts of from about 3 to 6 per cent and silver 97 to 94 per cent. Additional components, such as cadmium, aluminum, zinc, tin or antimony, may be used.

1,643,756, Carburizing Box, William B. Sullivan, of Detroit, Assignor to Chrobaltic Tool Co., a corporation of Illinois.

This patent describes a carburizing box having the wall 10 and cover portion made of cast metal and providing a plurality of ports in the walls

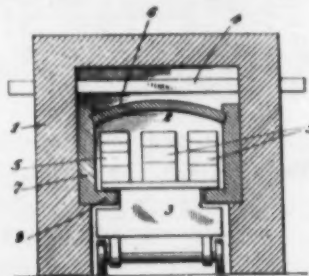


and cover which are closed by means of the sheet metal panels 13. The ports are rabbetted along the margins as indicated at 15 and the panels 13

are secured in place by a welding fillet, as indicated at 16. The object of the invention is to provide a carburizing box having the strength and endurance of cast iron and yet giving the advantage of lighter weight and easier handling, which is inherent in sheet metal, the cast iron frame work 10 providing the necessary strength and the steel panels 13 permit more rapid transfer of heat and give lighter weight.

1,643,808, Electric Furnace, Francis A. J. Fitzgerald, of Niagara Falls, New York, Assignor to Harper Electric Furnace Corp., a corporation of New York.

This patent describes an electric furnace constructed to permit a considerable quantity of heated material being quickly raised to a uniform temperature throughout its mass. The figure represents an embodiment of



the invention in the form of a tunnel kiln, 1 representing the outer casing of the furnace, 2 the tunnel through which the car 3 carrying the material 5 to be treated may pass. The resistors 4 are heated by an electric current and radiate their heat to the cover 6 of the panels which in turn radiate to the material 5. A lining 7 of high heat-conducting material is provided with baffles 8 extending into lateral recesses in the truck body.

1,644,828, Method of Annealing or Heat-Treating Steel or Other Metals, F. Walter Guilbert, of Detroit.

This patent describes a method of annealing or heat-treating steel or other metals, normalizing and annealing the same without subjecting the surface to oxidation and discoloration. The process is described as preventing the formation of oxide scales or discoloration on the surface of the steel by carrying out both the heating of the metal to the proper degree and the quenching of the metal in a partial vacuum.

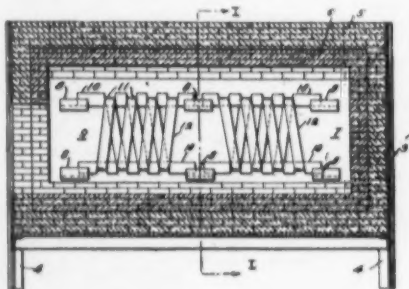
1,645,126, Process of Preparing Low-Carbon Alloys, Vere B. Browne, of Tarentum, Pennsylvania.

This patent describes a process for preparing low-carbon alloys, such as chromium or manganese alloys, in an electric arc furnace employing carbon electrodes. The process differs from that usually followed in an electric arc furnace by the use of a second slag which is not of a deoxidizing nature. The bath is refined in the usual manner by the use of an oxidizing slag and the first slag is then removed and replaced by a slag consisting largely of lime with sufficient fluorspar to impart the necessary fluidity. The alloying components are introduced into the bath while

the absorption of carbon is prevented by the oxidizing second slag. Thereafter a reducing character is imparted to the second slag by the addition of a non-carbon reducing agent, such as silicon, ferro-silicon or aluminum, to reduce the oxide components of the slag to the desired degree to recover completely the alloying metals, the electric power being cut off and the electrodes raised during the last step to prevent contamination by carbon.

1,645,293, Electric Furnace Resistor, Thomas A. Reid, of Wilkesburg, Pennsylvania, Assignor to Westinghouse Electric & Manufacturing Co., a corporation of Pennsylvania.

This patent describes a resistor furnace in which the resistor elements,



consisting of ribbons 12, are wound on spaced bars 10 and suspended from the walls of the furnace by means of insulating supports 8 embedded in the walls of the furnace.

1,643,321, Rail Steel, Joseph Kent Smith, of Detroit, Assignor to C. Harold Wills, of Marysville, Michigan.

This patent describes an alloy for the making of rail steels which will increase the life, strength and resistance to wear of the rails without the necessity for heat treatment of the same. The desired result is secured by intensifying the potential difference in the ferrite and carbide constituents of the steel. For this purpose an alloying ingredient, such as copper, is added, which will dissolve the ferrite and another alloying ingredient, such as molybdenum, which will intensify the action of the copper by the further solution of a little of the molybdenum. The molybdenum also strengthens the carbides by the formation of molybdenum-complex carbides. The steel rail produced from this alloy is of approximately normal weight per unit of length and has the physical properties requisite to withstand increased heavy service demands and long life without deviation from the usual fabrication practice. The preferred composition is substantially as follows:

	Per Cent
Carbon	0.35 to 0.75
Manganese	0.5 to 1.1
Copper	0.25 to 1.25
Molybdenum	0.07 to 1.0
Silicon, Sulphur and Phosphorus as in the usual practice	

THE ENGINEERING INDEX

Registered United States, Great Britain and Canada

Arrangements have been made with The American Society of Mechanical Engineers whereby the American Society for Steel Treating will be furnished each month with a specially prepared section of The Engineering Index. It is to include items descriptive of articles appearing in the current issues of the world's engineering and scientific press of particular interest to members of the American Society for Steel Treating. These items will be selected from the copy prepared for the annual volume of the Index published by the A. S. M. E. some 1,200

In the preparation of the Index by the staff of the A. S. M. E. some 1,200 domestic and foreign technical publications received by the Engineering Societies Library (New York) are regularly searched for articles giving the results of the world's most recent engineering and scientific research, thought, and experience. From this wealth of material the A. S. S. T. will be supplied with a selective index to those articles which deal particularly with steel treating and related subjects. Photostatic copies (white printing on a black background) of any of the articles listed may be secured through the A. S. S. T. The price of each print, up to 11 by 14 inches in size, is 25 cents. Remittances should accompany orders. A separate print is required for each page of the larger periodicals, but whenever possible two pages will be photographed together on the same print. When ordering prints, identify the article by quoting from the Index item: (1) Title of article; (2) name of periodical in which it appeared; (3) volume, number, and date of publication of periodical; and (4) page numbers.

ALUMINUM

CORROSION. The Protection of Aluminum and Its Alloys Against Corrosion. H. Sutton and A. J. Sidery. Engineering, vol. 124, no. 3218, Sept. 16, 1927, pp. 376-377. Describes methods of protection of aluminum against corrosion which have so far proved most successful in experience of authors; protection by anodic oxidation; protection by electro-deposited coatings.

ALUMINUM BRONZE

HIGH COPPER CONTENT. Aluminum Bronzes (Etude sur les bronzes d'aluminium), J. Boudloires. Revue de Metallurgie, vol. 24, nos. 7 and 8, July and Aug. 1927, pp. 357-376 and 463-473, 31 figs. Methods and results of an experimental study of heat reactions, electrical properties, density, hardness, micrography of aluminum alloys containing 80 to 95 per cent of copper; bibliography.

BLAST FURNACES

BLAST DRYING. The Use of Silica Gel As a Medium For Drying Blast. E. H. Lewis. Iron & Steel Inst.—Advance Paper, no. 9, Sept. 1927, 10 pp. Presents data on use of silica gel as medium for drying test obtained at Wishaw Works (Scotland) of Glasgow Iron & Steel Co., Ltd.; historical notes and bibliography.

BRITISH PRACTICE. British Blast-Furnace and Cupola Practice, J. E. Fletcher. Foundry Trade J., vol. 36, no. 18, Aug. 18, 1927, pp. 153-154. Fuel economy in furnace and cupola; need to utilize maximum heat.

CONTROL SYSTEM. Description of a Blast Furnace Control-System (Beschreibung einer Hochofen—Ueberwachungsanlage), F. Kretschmer. Siemens—Zeit., vol. 7, nos. 2, 3 and 4, Feb., Mar. and Apr., 1927, pp. 67-75, 155-161 and 198-205, 25 figs. Details of centralized electrical control system for

measuring and automatic recording of gas pressure volumes and temperatures, also CO₂ content of group of seven blast furnaces with their appurtenances.

DESIGN. Improved Furnace on Southern Ores, J. P. Dovel. Iron Age, vol. 120, no. 12, Sept. 22, 1927, pp. 782-784, 2 figs. Steeper inwalls, water cooled, permit more uniform stock distribution with corresponding gains in tonnage and lowered coke ratio.

IMPROVED. Wheeling Steel Corporation's New Furnace. Blast Furnace & Steel Plant, vol. 15, no. 9, Sept. 1927, pp. 444-445, 6 figs. Blast furnace features novel development in gas wasting; capacity equal to production of largest furnaces; bells operated by electric hoists.

BRASS

HEAT TREATMENT. Heat Treating Brass Parts in Process, K. C. Monroe. Am. Mach., vol. 67, no. 13, Sept. 29, 1927, pp. 491-494, 6 figs. Importance of proper heat-treatment on working and finishing qualities of brass employed for drawing and stamping purposes as demonstrated in experiments made by Bridgeport Brass Co.; experiments were made on regular process work over long period of time, and showed conclusively that annealing of brass between drawing operations must be considered as major operation requiring close attention, and that final product of accuracy and high-grade finish cannot be obtained without proper control of this detail.

PROPERTIES, UNIFORM. The Uniformity of Brass Alloys, E. R. Thews. Brass World, vol. 23, no. 9, Sept. 1927, pp. 289-292, 1 fig. Small fluctuations of main constituents strongly influenced by even little quantities of impurities; uniformity obtained by melting in large units.

CAST IRON

ALLOYS. Uses of Nickel and Chromium Cast Iron with Special Reference to the U.

S. A. (Ueber die Verwendung von nickel-und chromlegiertem Gusseisen mit besonderer Berücksichtigung der Vereinigten Staaten von Nordamerika), P. Oberhoffer and E. Piwowarsky. *Giesserei*, vol. 14, no. 35, Aug. 27, 1927, pp. 585-592. Authoritative summary and comments on achievements of Americans in technology of cast iron alloys; also original tests, chemical and metallographic studies by authors.

FLUIDITY. Test Bars to Establish the Fluidity Qualities of Cast Iron, C. Curry. *Am. Foundrymen's Assn.—Advance Paper*, no. 27-23, June 6-10, 1927, 18 pp., 14 figs. Definition, early investigation, description of test, application of test to nonferrous work.

PRODUCTION OF. Progress in the Production of High Duty Cast Iron, E. Piwowarsky. *Foundry Trade J.*, vol. 36, no. 18, Aug. 18, 1927, pp. 147-151, 1 fig. Existing specifications; causes of uncertainty of facts; two solutions offered; low melting temperatures vs. superheating; theories developed by science of crystallization; metal poured with a mould with variously heated sections; conclusions drawn from investigations of heated mold sections; relation between melting temperatures, superheating and contraction; relation between chemical composition and superheating; relation between melting temperatures; superheating, and contraction; conclusions drawn from superheating experiments; jolting of molten iron; theories based on formation of graphite above critical temperature; hypothetical explanation; process of producing high-duty cast-iron.

STRENGTH OF. The Strength of Cast Iron, J. E. Fletcher. *Foundry Trade J.*, vol. 36, nos. 570 and 571, July 21 and 28, 1927, pp. 69-72 and 89-92, 5 figs. Calls attention to variations in strength and gives typical examples; combined functions of total carbon and silicon; data presented refers to castings of about 1½ in. diameter having approximately same cooling ratio.

WORKABILITY. Hardness and Workability of Cast Iron (Ueber Härte und Bearbeitbarkeit im Gusseisen), W. Melle. *Giesserei Zeitung*, vol. 24, no. 17, Sept. 1, 1927, pp. 485-486, 4 figs. Importance of cutting tests for special, high grade cast iron and its determination by means of Kessner nearness-testing drill; defines workability in terms of depth of boring per 100 revolutions under strictly specified conditions and demonstrates by series of experiments, that it is function of Brinell hardness.

CASTINGS

ARTISTIC. Recent Artistic Iron Castings (Neuer Eisenkunstguss), G. Grundmann. *Giesserei*, vol. 14, no. 34, Aug. 20, 1927, pp. 573-575, 5 figs. Describes artistic work of Lauchhammer foundry in Saxony.

ARC-WELDED STEEL. vs. Replacing Castings with Arc-Welded Steel, J. F. Lincoln. *Can. Mach. & Mfg. News*, vol. 38, no. 14, Sept. 1, 1927, pp. 23-25. The advantages of arc-welded steel parts over those of cast iron or riveted construction are emphasized by the very definite savings in cost effected; work of the redesigning engineer of tremendous importance.

MANGANESE STEEL. Precision Equipment Finishes Manganese Steel Parts Rapidly. *Abrasive Industry*, vol. 8, no. 10, Oct. 1927,

pp. 320-323, 8 figs. Cleaning room equipment of Chicago Heights plant of Am. Manganese Steel Co.; selection and testing of grinding wheels.

ELECTRIC FURNACES

ANNEALING. Electric Furnace Used in Annealing Cylinders for Air Cooled Engines, I. S. Wishoski. *Fuels & Furnaces*, vol. 5, no. 9 June 1927, pp. 1199-1202, 2 figs. Electric furnace of recuperative return type with automatically operated pusher mechanism proves very efficient in annealing automobile engine cylinders.

ARC. The Oxidation Process in the Arc Furnaces (Beitrag zu den Oxydationsvorgängen im Lichtbogen-Elektroofen), K. v. Kerpely. *Centralblatt der Hütten u. Walzwerke*, vol. 31, no. 34, Aug. 24, 1927, pp. 471-475. Chemistry of process and its effect upon manganese, phosphorus, silicon and other iron ore ingredients.

STEEL. High Frequency Induction Melting, D. F. Campbell. *Iron & Steel Inst.—Advance Paper*, no. 1, Sept. 1927, 8 pp., 4 figs. Scope of high-frequency heating is expanding as rapidly as electrical machinery constructors can meet the requirements imposed upon them, and progress both in melting and heating of steel is being rapidly accomplished; its value is, however, already well established as a method of making crucible steel of remarkable homogeneity at a low cost, with elimination of the hard physical labor inseparable from present methods.

ELECTRIC WELDING

SPOT. Spot Welding of Dissimilar Metals, R. T. Gillette. *Welding Engr.*, vol. 12, no. 9, Sept. 1927, pp. 45-47, 6 figs. Uses of spot welding process; comparison with other methods; electrode material for dissimilar metals; electrode shape for unlike thicknesses.

ELECTRIC WELDING, ARC

"ALTERNARC" PROCESS. The "Alternarc" Cutting and Welding Process. *Welding J.*, vol. 24, no. 288, Sept. 1927, pp. 270-273, 4 figs. A description of the "Alternarc" machine (Holslag's transformer), "Newarc" electrodes and the "Alternarc" safety device.

BUILDING CONSTRUCTION. An Arc Welded Residence, J. G. Dudley. *Welding Engr.*, vol. 12, no. 9, Sept. 1927, pp. 51-53, 8 figs. A steel framed building with all joints welded, which offers many advantages over other types of building construction.

BUILDING CONSTRUCTION. Arc-Welded Wind Bracing Connections, W. A. Hakin and R. G. Richards. *Welding Engr.*, vol. 12, no. 9, Sept. 1927, pp. 40-44, 6 figs. Tests to determine the capacity of a given connection under high bending moments, and to evolve the requisite data for proper design.

FOUNDRIES

ELECTRIC STEEL. Preheating Reduces Melting Period, E. Bremer. *Foundry*, vol. 55, nos. 16 and 17, Aug. 15 and Sept. 1, 1927, pp. 626-630 and 674-677, 12 figs. Description of modern steel foundry. Aug. 15: Historical background of electric furnaces; plant of Burnside Steel Foundry Co. Chicago.

Sept. 1: Melting of metal and also annealing of castings accomplished in electrical furnaces.

FURNACES

INDUSTRIAL. Industrial Furnaces, V. J. Azbe. *Mech. Eng.*, vol. 49, no. 10, Oct. 1927, pp. 1079-1081, 6 figs. Importance of relative temperatures of heat-radiating and heat-absorbing media; effects on efficiency of low CO_2 and excess air; cost of steam for blowing.

OIL, GAS, AND ELECTRIC-FIRED. Oil, Gas, and Electric-Fired Furnaces, F. W. Manker. *Iron Age*, vol. 120, no. 12, Sept. 22, 1927, pp. 789-790 and 844-845. Advantages and disadvantages of each type analyzed for specific operations; control and atmosphere stressed.

FURNACES, HEAT TREATING

NON-CONTINUOUS. Furnaces for Forging and Heat Treating, M. H. Mawhinney. *Forging-Stamping-Heat Treating*, vol. 13 no. 9, Sept. 1927, pp. 374-376. More important factors to be considered in selection of suitable non-continuous furnace for forging or heat treating miscellaneous pieces that are variable in size; among the features covered are design and construction, burners, fuel saving, insulation and automatic control of fuel.

OIL-FIRED. Front Axles for Automobiles Uniformly Heated in Oil Fired Furnace. *Fuels & Furnaces*, vol. 5, no. 9, June 1927, pp. 1215-1216, 2 figs. Furnace of the walking beam type uniformly heats axles for stretching and flattening operations.

REFRACTORY LININGS. Refractory Linings for Forge and Heating Furnaces, M. C. Booz. *Fuels & Furnaces*, vol. 5, no. 9, Sept. 1927, pp. 1197-1198. Different types of refractories best adapted for certain kinds of services; all desirable properties not available in any one material and it is often desirable to use two or more refractories in combination to secure maximum service; open joints and flame impingement should be avoided; cracks should be repaired immediately.

HAMMERS

STEAM. Lubrication of Steam Hammers, D. C. Price. *Forging-Stamping-Heat Treating*, vol. 13, no. 9, Sept. 1927, pp. 360-361, 2 figs. Difficulties encountered in lubrication of steam hammers and means for overcoming; oil should be filtered and heated.

HEAT TREATMENT

AUTOMOBILE SPRINGS. Heat Treatment of Automobile Springs in Electric Furnaces. *Fuels & Furnaces*, vol. 5, no. 9, June 1927, pp. 1213-1214, 2 figs. Electrically heated furnace of the pusher type through which the springs are carried on short tubes pushed along in four parallel channels, has heating elements above and below the hearth.

IRON ALLOYS

ALUMINUM, EFFECT of. The Influence of Aluminum on an Iron-Carbon Alloy, A. B. Everest. *Foundry Trade J.*, vol. 36, no. 575, Aug. 25, 1927, pp. 169-173, 9 figs. Describes preliminary investigation at Univ. of Birmingham; results indicate range of

alloys which might be investigated in further detail with view to their commercial application.

CASE HARDENING. Case Hardening of Ferrous Alloys with Vanadium and with Cobalt (Cementation des alliages ferreux par le vanadium et par le cobalt). J. Laissus. *Revue de Metallurgie*, vol. 24, no. 8, Aug. 1927, pp. 474-484, 15 figs. Theoretical and experimental study showing that hardening with either of these metals produces a superficial layer, whose thickness can be increased by raising temperature or prolonging treatment, which resists corrosion by water and acids.

IRON-NICKEL. The Influence of Nickel and Silicon on an Iron-Carbon Alloy, A. B. Everest, T. H. Turner and D. Hanson. *Iron & Steel Inst.—Advance Paper*, no. 4, Sept. 1927, 29 pp., 31 figs. Account of investigation to obtain information concerning fundamental action of nickel, by studying its effect on simple iron-carbon-silicon alloys, before proceeding to the investigation on more complex cast irons, in which other elements always occur.

SILICON-CARBON. The Constitution of Silicon-Carbon-Iron Alloys and a New Theory of the Cast Irons, D. Hanson. *Iron & Steel Inst.—Advance Paper*, no. 6, Sept. 1927, 41 pp., 16 figs. Investigation carried out by author for Cast Iron Research Association on ternary alloys of iron containing 0 to 2 per cent of silicon and 0 to 4 per cent of carbons; it is shown that in ternary alloys, graphite and cementite can occur as stable phases, either separately or together, and limits of temperature and composition within which each occurs have been determined; theory of cast iron is developed with reference to ternary equilibrium of this alloys system, and is used to account for principal features of commercial iron-carbon alloys.

IRON AND STEEL

INDUSTRY, AMERICAN. The Economic and Social Development of the American Iron and Steel Industry, T. W. Robinson. *Iron & Steel Inst.—Advance Paper*, no. 11, Sept. 1927, 19 pp. Description of some of the more important changes that have affected manufacture of iron and steel which may well serve not only as a text of the progress of industry itself, but as a means of illuminating some of the reasons for American prosperity as a whole.

IRON CASTINGS

CLEANING. Cleaning of Castings (Gussputzverfahren in ihrer Entwicklung bis zur Gegenwart), K. Sipp. *Giesserei*, vol. 14, no. 36, Sept. 3, 1927, pp. 601-609, 27 figs. Evolution of processes for cleaning castings of sand, removing burrs etc.; critical description and operation costs of methods used in German foundries with particular reference to hydraulic power cleaning.

IRON, PIG

PRIMARY FINING, FINISHING. The Pig-Ore Process with Primary Furnaces (Das Roheisenerzverfahren mit Vorfrischern), E. Kiling. *Stahl u. Eisen*, vol. 47, no. 29, July 21, 1927, pp. 1197-1203, 5 figs. Detailed quantitative experimental study of chemistry, metallurgy, heat economy and costs of pri-

mary fining (with ore and lime) and finishing processes as practiced in Germany.

WORLD PRODUCTION. Iron and Steel Internationally Considered, W. J. Larke. West of Scotland Iron & Steel Inst.—Jl., vol. 34, no. 3, Jan. 1927, pp. 40-47 and (discussion) 47-50. Statistics and comment. Paper read before West of Scotland Iron & Steel Inst.

LEAD

CANADA. Lead and Zinc in Canada, T. W. Bingay and F. J. Alcock. Can. Min. & Met. Bul., no. 184, Aug. 1927, pp. 920-943, 13 figs. History and geology of lead and zinc in Canada; paper before Vancouver meeting of Empire Mining and Metallurgical Congress, Sept. 14, 1927.

LEAD ALLOYS

LEAD-TIN. Effect of Work and Annealing on the Lead-Tin Eutectic, F. Hargreaves. Engineering, vol. 124, no. 3218, Sept. 16, 1927, pp. 375-376. Experiments made to determine relationship between amount of softening action resulting from work at air temperature on specimen of lead-tin eutectic, and degree of working; effect of annealing at different temperatures for varying periods also determined.

MALLEABLE CASTING

STANDARDS. Tendencies in Malleable Iron Standardization (Ueber die Bestrebungen zur Normung von Temperguss), R. Stotz. Giesserei-Zeitung, vol. 24, no. 14, July 15, 1927, pp. 385-392, 18 figs. Compares mechanical properties of German malleable irons with those of American black and white heart iron; suggests that three quality standards, with proper minimum values of mechanical properties be recognized.

MANGANESE STEEL

PROPERTIES. Properties of Manganese Steel, J. H. Hall. Can. Machy. & Mfg. News, vol. 38, No. 14, Sept. 1, 1927, pp. 20-21. Outlines history, manufacture, use, and peculiarities of manganese steel, and at the same time explaining some of the problems that were overcome to make it commercially profitable.

MATERIALS, HANDLING

STEEL INDUSTRY. Keeping the Steel Industry Supplied with Raw Materials, L. S. Monroe. Indus. Mgmt. (N. Y.), vol. 74, no. 2, Aug. 1927, pp. 112-117, 20 figs. How coal, iron ore and limestone are handled in bulk.

MATERIALS, TESTING

INTERPRETATION OF. General Meaning of Tests of Materials (Die allgemeine Bedeutung der Werkstoffprüfung), W. Schmidt. V. D. I. Zeit., vol. 71, no. 32, Aug. 6, 1927, pp. 1123-1128, 14 figs. Bearing of tensile strength tests on study of structure of matter; effect of temperature and pressure on tensile strength of metals and viscosity of lubricating oils.

METALLOGRAPHY

ETCHING. Note on Cathodic Disintegration As a Method of Etching Specimens For Metallography, C. S. Smith. Inst. of Metals—Advance Copy, no. 438, 1927, 3 pp., 4 figs. Well-known phenomenon of cathodic sputtering can be used to develop the structure of metal specimens for microscopic examination; silver-copper alloys are particularly suited for etching by this process, which causes staining of copper-rich constituent as well as removal of the silver.

POLISHING AND ETCHING. Polishing and Etching Lead, Tin, and Some of Their Alloys for Microscopic Examination, J. R. Vilella and D. Beregekoff. Indus. & Eng. Chem., vol. 19, no. 9, Sept. 1927, pp. 1049-1052, 16 figs. This work forms part of a series of investigations on improved methods of polishing and etching conducted at the Union Carbide and Carbon Research Laboratories Inc.; in addition to present contribution, this investigation has resulted in development of method of polishing steel which does not drag out non-metallic inclusions; also in improved methods for polishing and etching iron-chromium alloys, copper and its alloys, and aluminum and its light alloys.

POLISHING MACHINES. A Metallographic Polishing Machine, O. E. Romig and J. C. Whetzel. Am. Soc. for Steel Treat.—Trans., vol. 12, no. 2, Aug. 1927, pp. 235-238, 1 fig. Available metallographic polishing machines were studied and many were tried, but there were disadvantages of slippage of belts and friction disks, excessive noise and vibration, all of which increased difficulty of polishing specimens; it was decided to construct a polishing machine free from these defects and one that would have sufficient power to polish large specimens such as those used for macro examination; horizontal disk type was decided on and machine of this type was built according to ideas of authors; resulting machine was very smooth running and gave very good results.

METALLURGY

HISTORY OF. Some Old Metallurgical Riddles, R. T. Rolfe. Metal Industry, (London), vol. 31, no. 4, July 20, 1927, pp. 75-77. Egyptian metal working and the mystery of the tabernacle.

MAGNETIC SEPARATION. Magnetic Separation Tests, B. W. Holman. Min. Mag., vol. 37, no. 2, Aug. 1927, pp. 73-86, 9 figs. A theory of magnetism is discussed, its practical applications illustrated, and the need for more research work on fundamental data shown.

METALS

FATIGUE. Fatigue Failure of Railway Materials. Metallurgist (Supp. to Engr.), Aug. 1927, pp. 123-124, 4 figs. From an article by Dr. Kühnel in V. D. I., Apr. 1927, p. 557.

PROPERTIES. Physical Properties of Engineering Materials. Power Engr., vol. 22, nos. 250, 252, 253, 254, 256, 258, Jan., Mar., Apr., May, July, Sept., pp. 27-29, 107-108, 145-146, 179-180, 255-257, 345-346. Nickel and nickel alloys; vanadium; bismuth; iron and steel.

RESEARCH. Material Research from Standpoint of Machining and Use (Werkstoff-Forschungen vom Standpunkte der Verarbeitung und der Verwendung), G. Weiter. Zeit für Metallkunde, vol. 9, nos. 6 and 7, June and July, 1927, pp. 232-237 and 265-274, 39 figs. Investigation of constants as guide to production and use of structural materials; of primary importance in behavior of materials in production are crystal structure, resistance to deformation and capacity of deformation at different temperatures; in use of materials in construction, stresses of purely elastic nature must be considered; points out inadequacy of usual testing methods with regard to use of structural materials, giving reason for failures of elasticity measurements.

STRENGTH AT HIGH TEMPERATURES. Experimental Reseraches on the Speed of Deformation of metals at High Temperatures (Recherches experimentales sur les vitesses de deformation des metaux aux hautes temperatures), P. Henry. Revue de Metallurgie, vol. 24, no. 8, Aug. 1927, pp. 421-442, 16 figs. History of such researches in Europe and America; report on experiments, at the laboratory of general chemistry of the Sorbonne of Paris, on the effect of torsional stresses on copper and steels at high temperatures, which resulted in formulas for solid copper at all temperatures and for steels and iron between 400 Deg. C. and 800 deg. C.; formulas extended to apply to tensile stresses at point of creep.

TEMPERATURE EFFECT on. Effect of Temperature on the Properties of Metals. Mech. Eng., vol. 49, no. 10, Oct. 1927, pp. 1111-1114, 9 figs. Progress report of joint research committee organized by the Am. Soc. of Mech. Engrs. and the Am. Soc. for Testing Materials; results of tests on thermal expansion of four classes of steel; comparative high-temperature tension tests on a carbon steel and on a chromium-molybdenum steel.

WORK-HARDENING PROPERTIES. Work-Hardening Properties of Metals, E. G. Herbert. Mech. Eng., vol. 49, no. 9, Sept. 1927, pp. 980-990, 26 figs. It is object of present work to correlate with operation of cutting tools certain well-established and generally recognized facts, chief among them being: metals are hardened by any process which deforms them so as to cause permanent change of shape while they are at low or moderate temperatures, a process referred to as "cold work;" that metals are deformed and are therefore hardened by cutting tools; that heat is generated by deformation of metals and in a preeminent degree by metal cutting operations; and that degree of hardness induced by working metals with cutting tools, or otherwise, is greatly influenced by temperature at which deformation takes place.

NICKEL STEEL

NICKEL-CHROMIUM. Magnetic and Other Changes Concerned in the Temper-Brittleness of Nickel-Chromium Steels, H. A. Dickie. Iron & Steel Inst.—Advance Paper, no. 2, Sept. 1927, 16 pp., 10 figs. Account of experiments carried out to discover how the magnetic properties, the specific electrical resistance, the specific volume, and the hardness of highly susceptible nickel-chromium steels are affected by various tempering treatments.

NON-FERROUS METALS

TENSILE TEST BARS. Methods for Gating Tensile-Test Bars of Sand-Cast Non-Ferrous Alloys, R. J. Anderson. Foundry Trade J., vol. 36, no. 18, Aug. 18, 1927, pp. 159-161, 10 figs. Various tests were made by writer with gating methods on a large number of commercial casting brasses, bronzes, and aluminum alloys, excepting high-shrinkage brasses of the type of aluminum brass and manganese bronze.

OPEN-HEARTH FURNACES

FLAT SUSPENDED ROOFS. Flat Suspended Open-Hearth Roof, A. L. Foell. Iron & Steel (Canada), vol. 10, no. 7, July 1927, pp. 210-211. Effect on furnace operation; advantages; details of furnace and roof; results on backwalls. Presented at Pittsburgh convention of Association of Iron and Steel Electrical Engineers.

REGENERATORS FOR. Regenerators for Open-Hearth Furnaces, F. H. Loftus. Blast Furnace & Steel Plant, vol. 15, no. 9, Sept. 1927, pp. 438-440, 2 figs. Form of checker installation described has its objective, increased efficiency, less regenerator space, reduction in cost of upkeep and fewer shut-downs.

OXYACETYLENE WELDING

AIRPLANE FUSELAGE. Gas Welded Fuselage Construction, N. Damours. Welding Engr., vol. 12, no. 8, Aug. 1927, pp. 34-36, 6 figs. Strong joints obtained with oxyacetylene torch act as a protection to passengers when engine trouble develops.

FLAMES. Melting Flames, Particularly the Acetylene Welding Flame (Zur Kenntnis der Schmelzflammen, insbesondere der Acetylene-Schmelzflamme), Pothmann. Autogene Metallbearbeitung, vol. 20, nos. 4 and 5, Feb. 15 and Mar. 1, 1927, pp. 50-57 and 67-73, 33 figs. Experimental data on relation between speed of welding to thickness of plate and properties of metal, effect of oxygen content, presence of water vapor and other injurious gases, chemical composition of acetylene and oxyacetylene flames and their structure; heat value of acetylene and many other gas and liquid flames which may be employed in welding.

OXYACETYLENE CUTTING

MECHANICAL METHODS. Economical Cutting Methods. Welding Engr., vol. 12, no. 9, Sept. 1927, pp. 35-37, 5 figs. Economies to be effected by mechanical control of oxyacetylene cutting of metals.

PIPE LINES

WELDED. An Unexpected Test. Oxyacetylene Tips, vol. 6, no. 1, Aug. 1927, pp. 2-3, 7 figs. Impact of a forty-length string of 16-in. pipe sliding down hill dramatically demonstrates value of weld.

PISTONS

LIGHT-ALLOY. Light-Alloy Pistons, G. D. Welty. Soc. of Automotive Engrs.—Jl., vol. 21, no. 2, Aug. 1927, pp. 146-150, 1 fig. Lightweight and high conductivity; design of aluminum pistons; installation; magnesium-alloy pistons.

SLAG

BLAST-FURNACE, USE AS STRUCTURAL MATERIAL. Utilization of Blast Furnace Slag in Highway Improvement, C. E. Bardsley. Mo., Univ. of. School of Mines & Met.—Bul., vol. 10, no. 1, Nov. 1926, 115 pp. History, manufacture, and use of slag as structural material: tests on blast-furnace slag, their interpretations and conclusions; recommendations, Bibliography.

STEEL

AUTOMOBILE BODIES. Steel Required in Automobile Bodies. Iron Age, vol. 120, no. 12, Sept. 22, 1927, pp. 779-781, 6 figs. Special qualities in sheets more successfully obtained by showing steel manufacturers exact requirements than by buying on strict specifications; developments in use of steel for automobile bodies by Edward G. Budd Mfg. Co.

CARBON, ABNORMALITY IN. Control of Normality in Plain Carbon Steels, F. G. Seifing. Mich. Eng. Experiment Station—Bul., no. 13, Sept. 1927, 25 pp., 35 figs. Describes experiments in which specimens from same bar of either normal or abnormal steel have been made abnormal or normal by merely changing heat treatment; furthermore, it is shown that a temperature range exists in iron-carbon diagram in which complete dissolution of cementite in steel takes place and that separation into constituents iron and cementite is difficult even by full annealing treatment.

COLD-ROLLING. The Influence of Cold-Rolling and Subsequent Annealing on the Hardness of Mild Steel, C. A. Edwards and K. Kuwada. Iron & Steel Inst.—Advance Paper, no. 3, Sept. 1927, 17 pp., 15 figs. Describes experiments to determine influence of varying degrees of cold work, in the form of cold-rolling, in the direction of increasing the hardness of mild steel and the temperatures at which this additional hardness is removed; material used for experiments was a low-carbon steel sheet 3 ft by 2 ft., and approximately 1.3 mm. in thickness.

HARDNESS. The Work-Hardening of Steel By Abrasion, E. G. Herbert. Iron & Steel Inst.—Advance Paper, no. 7, Sept. 1927, 12 pp., 12 figs. Describes an investigation into hardness induced by severe abrasion in locomotive tires and rails, and in hardened steel gears and cams from motor-cars; hardness induced by wear is compared with the "maximum induced hardness" measured by a recently developed test made with pendulum hardness tester.

STRESS, PROLONGED. The Behavior of Mild Steel Under Prolonged Stress at 300 Deg. C., W. Rosenhain. Iron & Steel Inst.—Advance Paper, no. 12, Sept. 1927, 6 pp., 8 figs. In connection with study of intercrystalline cracking in boiler plates, prolonged exposure tests under loads ranging from one-third to two-thirds of the normal ultimate stress have been carried out in air at a temperature of 300 deg. C., which has been maintained almost uninterruptedly for over five years; material used was a mild steel strip containing 0.106 per cent of carbon, trace of silicon, and 0.395 per cent of man-

ganese with very low impurities, and test-pieces in various conditions of heat treatment were employed; results of tests.

STRESSES, PROLONGED. The Behavior of Mild Steel Under Prolonged Stress at 300 Deg. Cent., W. Rosenhain. Engineering, vol. 124, no. 3219, Sept. 23, 1927, pp. 409-410. Experiments which authors have undertaken have been devised in order to determine effect of prolonged application of stresses to mild steel at temperature of 300 deg. Cent., particularly with view to determining whether stresses well below normal tensile strength will cause failure if applied for very long time.

TEMPERING. On the Mechanism of the Tempering of Steels, T. Matsushita and K. Nagasawa. Iron & Steel Inst.—Advance Paper, no. 10, Sept. 1927, 12 pp., 10 figs. In the course of investigation of physical properties of quenched steels during tempering, authors observed some unexpected facts which have an important bearing on elucidation of phenomenon of tempering; present paper contains a description of these phenomena, and also a new view concerning mechanism of tempering. Bibliography.

STEEL CASTINGS

FEEDING AND GATING. The Feeding and Gating of Steel Castings, A. Rhydderch. Foundry Trade J., vol. 36, no. 578, Sept. 15, 1927, pp. 233-236. Introduction to fundamental principles and considerations in gating and feeding of steel castings; follows path of metal from time it leaves ladle until castings are completed.

STEEL FOUNDRIES

EQUIPMENT MAINTENANCE. Details of a Simple Equipment Record System Used in a Large Steel Foundry, J. Thomson. Indus. Eng., vol. 85, no. 9, Sept. 1927, pp. 415-419 and 435, 8 figs. Necessity for keeping equipment in perfect working condition and study of system in use by Hubbard Steel Foundry Co., East Chicago, for equipment maintenance records.

STEEL, HEAT TREATMENT OF

BIBLIOGRAPHY. Books on the Heat Treatment of Steel, E. H. McClelland. Forging-Stamping-Heat Treating, vol. 13, no. 9, Sept. 1927, pp. 369-371. Treatises written in English, French, and German, dealing with the subject in all its branches; most of the publications are modern.

EFFECT OF. The Heat Treatment of Various Steels, L. O. Miller. Forging-Stamping-Heat Treating, vol. 13, no. 9, Sept. 1927, pp. 362-365. Effects of various chemical elements on the method of heat treatment and resultant physical properties of steels.

HUMP METHOD. The Hump Method of Heat Treating, J. W. Harsch. Forging-Stamping-Heat Treating, vol. 13, no. 9, Sept. 1927, pp. 372-373, 4 figs. Description of a means for determining the critical point based on the expansion and contraction of steel when subject to heat; chart records change in object.

STEEL INDUSTRY

GERMAN STEEL TRUST. The Steel Trust of Germany (Die Vereinigten Stahlwerke), H. Meis. Glückauf, vol. 63, no. 17, Apr. 23, 1927, pp. 603-616, 4 figs. History of formation of Vereinigte Stahlwerke A. G. in 1926; history of its member companies and description of their resources; present organization, activities, recent balance statements. See also article entitled Vereinigte Stahlwerke A. G., Düsseldorf, in Iron & Coal Trades Rev., vol. 115, nos. 3105 and 3106, Sept. 2 and 9, 1927, pp. 325-328 and 359-362, 14 figs.

STEEL WORKS

ROLLER STRAIGHTENING MACHINES. The Demag Roller Straightening Machines. Engineering, vol. 124, no. 3216, Sept. 2, 1927, pp. 295-296. In modern practice, bars are straightened by means of rollers by process similar to that employed in sheet-metal straightening machines; working time is then reduced to that required for one or two passages through rolls, second operation on press only being necessary in isolated cases; two distinct types of machine are employed, one having rolls supported on one side only, and other with rolls supported at each end between columns; these machines are manufactured by Deutsche Maschinenfabrik "Demag," of Duisburg.

WILLYS-OVERLAND, TOLEDO. Willys-Overland Forge and Treating Shop, C. Longenecker. Forging-Stamping-Heat Treating, vol. 13, no. 9, Sept. 1927, pp. 355-359, 6 figs. Describes new forge and heat treating shop of Willys-Overland Co., Toledo; possesses many features novel to plants of this nature.

TIME STUDY

ROLLING MILLS. Controlling Operation Through Time Keeping (Betriebskontrolle durch Zeitmessung), A. Körver. Centralblatt der Hütten u. Walzwerke, vol. 31, no. 35, Aug. 31, 1927, pp. 487-492, 4 figs. Examples of and proposals for use of time recorders, with circular charts or band records, in operation of rolling mills.

TOOL STEEL

TEMPERING. Effect of Silicon, Nickel, Chromium, and Tungsten on the Tempering of Tool Steel (Der Einfluss von Silizium, Nickel, Chrom und Wolfram auf die Härtung von Werkzeugstahl), W. Haufe. Stahl u. Eisen, vol. 47, no. 33, Aug. 18, 1927, pp. 1365-1373, 7 figs. Report on two series of experiments made at the Krupp works in Essen; specimens were subjected to repeated tempering until cracks appeared; relations between composition, annealing temperatures, number of temperings and increase in volume of hypo- and hyper-eutectoid steels; study of fracture structure.

WELDING

LARGE MACHINE PARTS. Arc Welding Eliminates Castings in A.-C. Machines, E. S. Henningsen and A. P. Wood. Elec. Wld., vol. 90, no. 6, Aug. 6, 1927, pp. 257-259, 8 figs. Designers are endeavoring to elimi-

nate castings wherever possible in alternating-current generators and motors and to substitute rolled-steel plate and structural steel fabricated by arc welding or bolting.

MULTIPLE-OPERATOR PLANTS. Multiple-operator Arc Welding Plants for A. C. and D. C. Supplies, C. H. S. Tupholme, Mech. World, vol. 82, no. 2119, Aug. 12, 1927, p. 109, 1 fig. Types of control for a. c. and d. c. plants.

NONFERROUS. Nonferrous Welding. Metallurgist (Supp. to Engr.), Aug. 1927, pp. 114-115. Brief discussion of principle involved.

PHOTOGONIOMETERS. A Universal X-ray Photogoniometer, J. D. Bernal. Jl. of Scientific Instruments, vol. 4, no. 9, June 1927, pp. 273-284, 4 figs. Combining: apparatus for single crystal rotation photographs; Laue photographs; X-ray spectrometry; powder photographs; photographs of crystal aggregates, metals, materials, etc.

PHOTOGRAPHS. X-Ray Photographs (Röntgenshattenbilder), V. M. Schwarz, Zeit. für Metallkunde, vol. 19, no. 5, May 1927, pp. 215-218, 12 figs. Discusses X-ray photographs of aluminum sand-cast and dye-cast specimens, of welds and of other materials and defects.

PIPE LINES. Welding Pipes Lines in Building, H. E. Wetzell. Iron & Steel (Canada), vol. 10, no. 7, July 1927, pp. 216-218, 6 figs. From a paper read before meeting of Gas Products Association, French Lick Spring, June 21, 1927.

REFRIGERATOR PARTS. Domestic Refrigeration—A New Industry. Oxy-Acetylene Tips, vol. 6, no. 1, Aug. 1927, pp. 12-20, 35 figs. Description of Electrolix system and welding jobs done on its parts.

RIVETING, vs. Welding and Riveting Compared as to Economy (Wirtschaftlicher Vergleich der Schmelzschweißung und der Nietung), W. Strelow. Maschinenbau, vol. 6, nos. 11, 12 and 13, June 2, 16 and July 1, 1927, pp. 549-553, 610-614 and 664-666, 35 figs. Detailed time and cost analysis, mostly in graphical form, based on German practice.

STEEL MANUFACTURE. Welding a Factor in Steel Manufacture. Can. Machy. & Mfg. News, vol. 38, no. 7, Aug. 18, 1927, pp. 17-24, 14 figs. Utility of welding process in construction, maintenance, operation and dismantling of open hearth furnaces is explained to emphasize economies possible from use of welding art.

STEEL, SPOT. Spot Welding of Dissimilar Metals, R. T. Gillette. Gen. Elec. Rev., vol. 30, no. 9, Sept. 1927, pp. 443-445, 6 figs. Uses of spot welding process; comparison with other methods; electrode material for dissimilar metals; electrode shape for unlike thicknesses; tests.

TANKS. Safe, Economical Storage for Fuel Oils, T. E. De Pew. Welding Engr., vol. 12, no. 8, Aug. 1927, pp. 37-40, 11 figs. Welded rectangular tanks of over 100,000 gallons capacity solve the storage problem at low construction cost.

TEMPLATES FOR PIPE FITTINGS. Templates for Pipe Fittings. Oxy-Acetylene Tips, vol. 6, no. 1, Aug. 1927, pp. 4-8, 10 figs. Patterns for bends, tees and branches can be quickly made.

News of the Chapters

STANDING OF THE CHAPTERS

DURING the month of September there were 120 new and reinstated members, while 37 were lost through arrears, resignations and deaths, leaving a net gain for the month of 83 members. The total membership of the Society on October 1, 1927, was 4,736.

In the following tabulation there appears the relative membership standing of the 32 chapters and 3 groups of the Society as of October 1, 1927:

GROUP I		GROUP II		GROUP III	
1. Detroit	499	1. Dayton	136	1. Tri-City	84
2. Chicago	414	2. Hartford	125	2. Los Angeles	81
3. Pittsburgh	339	3. Milwaukee	123	3. New Haven	77
4. Philadelphia	330	4. Canton-Massillon	113	4. Washington	71
5. Cleveland	315	5. Lehigh Valley	112	5. Worcester	68
6. New York	288	6. Golden Gate	107	6. Southern Tier	63
7. Boston	244	7. Indianapolis	95	7. Rochester	61
		8. Cincinnati	92	8. Rockford	59
		9. St. Louis	90	9. Columbus	57
		10. Syracuse	86	10. Toronto	57
		11. Montreal	67	11. Providence	54
		12. Buffalo	67	12. Fort Wayne	41
		13. North-West	52	13. Schenectady	38
				14. Springfield	34
				15. Notre Dame	24

GROUP I—The chapters in this group all maintained the same order of arrangement as in the report published in the October issue of TRANSACTIONS. Detroit still heads the list with a net gain of 15 for the month; Chicago, second, with a net gain of 9 and New York with a gain of 8.

GROUP II—Dayton is still the leader of this group, the first three chapters remaining in the same position as last month. Canton-Massillon with a gain of 5, passed Lehigh Valley and is now in position 4. St. Louis with a gain of 7, the largest of any chapter in this group, passed Syracuse and is now in position 9.

GROUP III—Fort Wayne showed the largest net gain of any member of this group, having 4 new members and passing Schenectady, advancing from 13th to 12th place. The other members of the group, headed by Tri City and Los Angeles, remain in the same positions as in the report of last month.

BOSTON CHAPTER

The October Meeting of the Boston Chapter was held at Massachusetts Institute of Technology, Cambridge, on October 7, dinner being served, as usual, to about 75 members in the Walker Memorial.

After the business meeting at which a report of the Detroit Convention and Exhibition was given by the Chapter Delegates, the evening program was held in Room 5-330 of the Naval Architectural building. Dr. Homerberg, chairman of the Educational Committee, reported that some 60 members had taken advantage of the opportunity offered them and had signed up for the Boston Chapter educational course in elementary metallurgy. This course, which is being given under the auspices of the Massachusetts Institute of Technology by the instructing staff of that Institution, starts October 7 to continue for twenty-four weeks. Dr. S. W. Stratton, President of the Institute, has expressed himself as highly in favor of this scheme of instruction and has placed the facilities of M. I. T. at the disposal of the local Chapter.

Dr. Waterhouse spoke in detail regarding the lectures to be given during the course and expressed the wish that the attendance would be large and regular in order to compensate, to some extent at least, for the great amount of preparatory work which has been done by the lecturers and officers of the Chapter. He also announced that although only members of the A. S. S. T. were admitted to the Course, it was felt by the Executive Committee that the Sustaining members, due to their generous support to the Chapter, should be allowed to send up to five of their employees who were not individual members, each, of course, to pay the regular fee of \$10.00. This opportunity was taken advantage of by several of the Sustaining members.

Robert E. Belknap, local representative of the Bethlehem Steel Company, announced that he would give three prizes of \$10.00 each for the best paper or written discussion covering each of the major subjects of the course, namely, general metallurgy, physical testing and metallography, the papers to be submitted to chairman Hawkridge at the completion of each section of the course.

The honored guest of the evening was George A. Richardson, manager of technical publicity of the Bethlehem Steel Co., who made his fourth appearance before the Boston Chapter. He entertained for nearly two hours showing motion pictures taken at the various plants of his company. During his talk he covered the operation of the blast furnace, Bessemer and open-hearth steel practice and the manufacture of sheets and tin plate. At the close of the meeting Mr. Richardson was given a rising vote of thanks for the splendid manner in which he handled his subject, and was assured that the members would be glad to see him again as soon as his new pictures were released.

H. E. Handy.

CHICAGO CHAPTER

On Thursday evening, October 13, 1927, the Chicago Chapter held its first regular meeting starting the 1927-28 season. Dinner was served at the City Club to 145 members and guests, a number of members coming after dinner made a total attendance of 175.

Samuel M. Havens, works manager of the Ingalls Shepherd division

Wyman Gordon Company, gave a memorial address to the memory of our deceased member, Arthur G. Henry, secretary Chicago Chapter, and founder member of the National Society, who dropped dead in the course of his duty on October 5.

A subscription was started after the memorial address to raise funds to place a suitable marker upon the grave of Mr. Henry indicating his connection with the Society during his life.

Our delegate to the Annual Convention, Ray Mau, made his official report stating that our present chairman, T. E. Barker, had been nominated for National Director for two years and of the huge success of the 1927 convention and exhibit.

J. A. Comstock of the Peoples Gas Light and Coke Company was elected to fill the unexpired term of our deceased Mr. Henry.

Dr. John A. Mathews, Vice-President of the Crucible Steel Company of America, gave an excellent paper illustrated with Lantern Slides, the subject being "Importance of Chromium in Steel Metallurgy." Dr. Mathews brought out many interesting points as to the uses of Chromium in steel making and its various effects upon different types of steels. At the conclusion of Dr. Mathews' paper a very interesting discussion followed. The paper was very well received by all present, everyone feeling that they had gained new knowledge from this interesting subject.

A. M. Steever.

CLEVELAND CHAPTER

The second regular meeting of Cleveland Chapter was held Friday, October 21, in the rooms of Cleveland Engineering Society in Carnegie Hall. Chairman H. H. Smith presided.

A report of the Membership Committee was made by chairman D. M. Gurney, who called on each member to endeavor to get a new member.

The speaker of the evening, Ward T. Van Orman of the Goodyear Tire & Rubber Co., National and International Balloon racing champion, delivered an extremely interesting talk. Mr. Van Orman brought out in his talk how the air currents vary at different altitudes and how the balloonist is able to avail himself of these conditions to travel in certain directions at maximum speed. Different devices and instruments for aerial navigation were described and the point was made that the balloon serves as a laboratory for experiments and tests for these instruments.

The possibilities of lighter than air craft were discussed and compared with airplanes. Mr. Van Orman stated that it was within the range of possibility to build an airship which could carry fuel enough and have a cruising range of round the world.

The number of questions asked was decided proof of how well the talk was enjoyed.

About 100 members were present, of whom about twelve had dined together preceding the meeting.

J. S. Ayling.

DAYTON CHAPTER

At the first of the present year's meetings of the Dayton Chapter held Monday evening, September 12, two innovations were put into effect. In

the vernacular of the day both "went over big." The first was an informal dinner and coffee talk; the second was a five minute educational talk before the regular meeting.

Fifty-five members enjoyed a good dinner at the Dayton Engineer's Club. While the second cup of coffee was being consumed R. E. Maeder, Research Chemist, of Delco Light Co., talked informally and entertainingly on "Chromium Plating." Mr. Maeder described some of the problems he had encountered in securing a satisfactory plate and briefly outlined the method. For nearly an hour the members discussed the talk.

Adjournment was then made to the assembly hall where the regular meeting was scheduled for 8 o'clock. The first of a series of educational talks on metallography was given by J. B. Johnson, Chief of Material Section, Air Corps, Wright Field. His subject was "The Nature of Ferrite." Mr. Johnson presented and illustrated his subject so well that every member present is now familiar with the first of the metallographic constituents.

The speaker of the evening was Frank B. Lounsberry, vice president of the Atlas Steel Corporation, who gave a practical and extremely interesting talk on "High Speed Steel and Oil and Water Hardening Tool Steels."

Mr. Lounsberry stressed the factors in the choice of a tool steel. He called attention to the importance of (1) analysis and requirements of the job, (2) the simplification of the various grades, (3) the quality and uniformity of the tool steel and (4) the service rendered by the supplier. He emphasized that tool steel should be inventoried by grades, not by brands, and should be sent to the hardening room with definite information as to the type of the steel. Each type of tool should have a definite heat treatment and in this connection an accurate record should be kept of the properties and performance of the tool. Good tools are the result of a hearty cooperation between the hardener and the tool designer. It is very essential that special importance be attached to fillets and to the absence of abrupt changes of section which might result in cracking in hardening. About 100 members attended the regular meeting.

F. T. Sisco.

HARTFORD CHAPTER

The October meeting of the Hartford Chapter A. S. S. T. was held Tuesday, October 11th, at the Hartford Electric Light Auditorium with Earl A. Ryder, assistant chief engineer, of the Pratt & Whitney Aircraft Corporation who described "High Performance Air-Cooled Aviation Engines." Mr. Ryder illustrated his talk with lantern slides of the "Wasp" and "Hornet" engines which are products of his company. For an hour and three quarters of lecture and discussion Mr. Ryder interested his hearers and answered their many questions which ranged from requests for technical information on power, torque etc. to "how much does it cost to run one of these engines." Mr. Ryder's modesty in regard to the phenomenal records made by this engine in the United States Naval Service was helped out by A. H. d'Arcambal who reviewed some recent performances which have been published by the newspapers.

The Pratt and Whitney Aircraft Corp. exhibited a "Wasp" engine,

completely assembled ready for installation in a plane with all accessories. The motor develops 425 horsepower at 1900 rpm at sea level and weighs 650 pounds. Compared to a Liberty motor which has the same power, the saving in weight through the air-cooled design and other features of the fixed radial type of engine amounts to nearly 500 pounds. It is only through the best applications of design, manufacture and heat treating that this is possible. Several of the major detail components were also available for the inspection of the audience who crowded around the motor and other parts for nearly an hour after the close of the meeting.

Over 300 members and guests crowded the auditorium to its capacity and made a record for attendance for a regular meeting. The interest in this meeting brought out many public officials, aircraft line executives and flyers, all of whom voted the meeting one of the most practical and instructive that had been heard on such a subject.

F. G. Hughes, Nominee for National President, took the opportunity to bring a brief message from the National Society. The Attendance prize of a chime clock was presented to E. C. Davis of the Hartford Empire Co., who won the September meeting contest and A. C. Schmeltzer of the Pratt and Whitney Co. won the October prize which was an electric chafing dish.

The next meeting will be held November 8th with Mr. William Finkl of the A. Finkl & Sons of Chicago as speaker on "Heat treatment of Alloy Steel Die Blocks."

The yearly program bulletin has been issued and includes a roster of the Hartford Chapter members.

R. Stanton.

LOS ANGELES CHAPTER

The October meeting of the Los Angeles Chapter was held Thursday, October 13, in the Banquet Hall of the Los Angeles Creamery, 12th and Towne Avenue. The meeting began at 6:30 with an excellent dinner and was enjoyed by everyone of the hundred members and guests present.

Immediately following the dinner, the secretary made his report; the Chapter's bills were also read and ordered paid.

After the report of the secretary, Mr. Hampton, our genial chairman and delegate to the National Convention, made his report of the Convention. From what Wade stated, the Convention surely must have been a very impressive and most interesting one.

At this meeting, we had several men with us whom the Chapter members were anxious to hear speak.

H. W. Westsmith, editor of the "Oil Bulletin," was present at this meeting, and he was called upon to speak. He gave a short but interesting talk, and assured the chapter that he would be only too glad to lend his services in any way he could to further the interests of the chapter and to spread to as many as he could the value of the work our Society was doing.

We were fortunate in also having at this meeting Mr. O'Brien of the Los Angeles Chamber of Commerce. Mr. O'Brien told us of the efforts the Chamber of Commerce had already put forth for our Chapter by extensive correspondence with National Headquarters, and he assured us that the

Chamber of Commerce would be glad at any time to lend its support to our own efforts in an attempt to bring a semi-annual Convention to Los Angeles.

After Mr. O'Brien's interesting talk, J. V. Coulter of Golden Gate Chapter was introduced. Mr. Coulter told us of the extensive program laid out for the coming year by the Golden Gate Chapter. He assured Los Angeles Chapter that Golden Gate would be glad to lend its efforts, so far as they could, to helping us bring a semi-annual Convention to Los Angeles. He stated that he did not wish to commit Golden Gate Chapter, but he felt certain that they would do everything they could to help us in such an attempt. After Mr. Coulter's talk, Mr. Moody, formerly of Golden Gate Chapter, made a short talk. We are glad to have Mr. Moody with us.

Following these several speakers, the chairman introduced Owen K. Parmiter, chief metallurgist of the Firth-Sterling Steel Co., who gave a most interesting paper on "Stainless Steels" and "Alloy Steels." His interesting paper was fully enjoyed by everyone present, and we feel we were very fortunate in being able to have Mr. Parmiter speak before our Chapter.

After reading his paper, Mr. Parmiter held open discussion for quite a long while. The discussion was fast and furious and Mr. Parmiter answered the many questions with an ease and confidence that clearly demonstrated his mastery of the subject.

The following committee was appointed to investigate the question of the semi-annual Convention to the Pacific Coast: Carl H. Fromme, chairman, Chas. J. Wild, Harvey Hewitt, Bill Nelson.

The above committee has been instructed by Mr. Hampton to confer with Mr. Cook of the Chamber of Commerce and report to the Chapter at the next meeting.

This October meeting was probably one of the most interesting in the history of our Chapter.

H. V. Ruth.

PITTSBURGH CHAPTER

The Pittsburgh Chapter held its October meeting on the evening of the 13th in the French Room of the William Penn Hotel. The meeting was preceded by a dinner in the cafeteria and several reels of movies depicting the progress of the telephone and the development and uses of the radio.

In the absence of the chairman, J. P. Gill, vice-chairman, W. I. McInerney, presided at the meeting, and, after the usual business session, welcomed A. O. Schaefer, assistant engineer of tests of the Midvale Company, as the speaker of the evening. Mr. Schaefer chose as his subject, "The Manufacture and Heat Treatment of Large Forgings." He said in part:

With the signing of the Treaty for the Limitation of Naval Armaments, the manufacture of large forgings for naval ordnance and armor plate stopped and the large forging shops were left idle awaiting the development of some use for them. This was not long in coming. Steam boilers, using forged steel drums; larger steam turbine units for power stations, calling for correspondingly heavier forgings; high pressure vessels were developed for cracking crude oil, etc., and for all these purposes the steel maker has been asked to produce larger forgings, of more variation in design and of more unusual properties.

The manufacturing history of any application of iron and steel begins in the melting furnace, and that of large forgings is no exception. Some of the important points are the necessity of having sound ingots of suitable proportions for subsequent forging operations; the use of both the basic and open-hearth furnace; the importance of right pouring temperature in the prevention of excessive segregation and the use of different types of molds.

As to the forging operation, if the ingot is not to be forged immediately, it is best to cool it very slowly, preferably in an annealing furnace, thus preventing stresses and strains set up by solidification if cooled too rapidly. In heating the ingot for forging, a ear-bottom furnace is most convenient, any fuel may be used but the flame should be greatly reduced and well baffled so as not to impinge on the surface of the unit. Such large masses must be heated slowly and evenly and soaked thoroughly until the mass has become of uniform temperature, the correct forging temperature depending, of course, upon the composition of the steel.

The proper heat treatment for a forging depends on many factors, such as its size, shape, composition and intended use. Each type of forging presents its own individual problems and calls for special heat treatment, because so many variables are concerned.

At the conclusion of this very much appreciated address, a general discussion ensued, which included a number of points brought out by the speaker. After the discussion, the meeting adjourned with a rising vote of thanks to Mr. Schaefer.

H. L. Walker.

PHILADELPHIA CHAPTER

The Philadelphia Chapter of the Society held the first meeting for the 1927-28 season on September 14 at 8:00 P. M. at Temple University. This was in the nature of a special meeting designed to promote a closer co-operation between Temple University and the Chapter concerning the course in heat treatment and metallography of steel, offered at the University under the auspices of the Chapter.

The dinner preceding the session was attended by sixty-eight members and guests of the Chapter, and was served in the main dining room of the University. Immediately after the dinner a group of those present was taken to the metallurgical laboratories where demonstrations under the auspices of H. C. Knerr, director of the course, were given. These included microscopic examinations, hardness tests, gas furnaces in operation under the direction of Mr. Ostermann of the American Gas Furnace Co., Dilatometer tests under the direction of S. P. Rockwell using his invention, the volerit apparatus, and demonstration of the working of an Ajax-Northrup high frequency furnace. All of the apparatus used is part of the equipment of the laboratory.

The speakers at the meeting were President Buery of Temple University, Prof. Bradley Stoughton, professor of metallurgy of Lehigh University, D. McLean, engineer Westinghouse Electric & Mfg. Co., Horace C. Knerr, consulting metallurgist and director of the course, and the chairman of the Chapter, James R. Adams. After the meeting a second group was shown through the laboratories.

The first regular meeting for the season was held at the Engineers' Club on Friday evening, September 30. This meeting proved to be a wonderful start for the year. It was necessary to put up a S. R. O. sign before the meeting started.

The speaker of the evening was Geo. Richardson of the Bethlehem Steel Co., who gave an illustrated talk on the "Manufacture of Iron and Steel." This talk was illustrated with six reels of exceptionally fine moving pictures. Several of the reels depicting the manufacture of tin plate at the Sparrows Point plant of the Bethlehem Steel Co. were shown for the first time and were so rich in detail especially concerning mechanical working that it is recommended that other Chapters should try to get a showing of them when possible.

The pictures fitted admirably into the plans of the Chapter's program committee under the chairmanship of Dr. H. C. Boynton, which is to present to the Chapter during the year a composite study of iron and steel starting with the manufacture and going on in progressive steps to hardness testing, etc. One meeting at least is to be devoted to non-ferrous metallurgy.

The Chapter has published the Year Book for 1927 and feels certain pride in its latest effort along that line. The booklet includes the names of all Chapter members, a resumé of the course in heat treatment and metallography of steel at Temple University some notes concerning the Society and some advertisements chiefly of a local nature. It would be a pleasure to send copies to anyone desiring them, and it will be done if requests are sent to A. W. F. Green, Secretary Philadelphia Chapter, 407 Shoemaker Road, Elkins Park, Philadelphia, Pa.

Arthur W. F. Green.

ROCHESTER CHAPTER

The first regular meeting of the season was held at the Hotel Osburn on September 12 and was preceded by the usual informal dinner. There were approximately twenty-two members and visitors present.

As there was no business for transaction, our chairman, Mr. Van Vechten, at once announced the speaker of the evening, S. C. Spalding, metallurgist, Halcomb Steel Co., Syracuse, New York.

Mr. Spalding took as his subject "Carburizing," first tracing the development, historically, of steel making processes. Following this he explained the three different methods in use for the production of a hard case on low carbon and alloy steels, finally describing the various types of steels being used for effective carburizing; namely, nickel (1 to 5 per cent), low carbon, chromium-nickel, molybdenum, chromium, etc. A very complete description was also given of the materials more commonly used in carburizing.

His talk was accompanied by some very interesting slides showing the structures obtained through different carburizing treatments. These slides were shown with our new Bausch & Lomb Balopticon and were projected on a new screen, both recently purchased by our chapter.

Following the talk a very lively discussion took place. *H. G. LeClaire.*

The second regular meeting of the chapter was held on October 10 and was preceded by dinner at the Hotel Osburn. Following the dinner retirement was made to the Assembly Hall and it was indeed gratifying to note an attendance so early in the season of approximately fifty members and visitors.

After reports from the delegate and others who attended the National Convention at Detroit had been given the chairman introduced as speaker of the evening C. B. Callomon, Manager of Alloy Sales, Allegheny Steel Co., who gave us a most interesting talk on the subject of "Stainless Iron." Following are excerpts from the lecture, also questions and answers as brought out in the discussion.

"The subject of corrosion is one on which many scientific minds have worked. There are two modern methods of combating corrosion; the older theory is one which through common use has come to be called the carbonic acid theory, and until recent times it has been used more or less scientifically to explain every form of corrosion, its exponents going out of their way frequently to work out involved chemical reactions which would give it truth. Briefly, it sets forth that corrosion, or as it is commonly spoken of, rusting, is always instituted through the agency of an acid.

"In describing stainless iron and steel the speaker stated that stainless steel contains from 0.30 per cent carbon up, while stainless iron is a product containing under 0.12 per cent carbon, and generally under 0.10 per cent carbon. Stainless steel must be heat treated and polished. It is corrosion-resisting and abrasion-resisting to a remarkable extent. Its cost does not only permit its consideration but its actual commercial use. This product is produced by some fifteen companies. In the annealed condition, stainless steel has a tensile strength is 175,000 pounds per square inch. Stainless iron may be spun, welded, soldered, etc. It is air-hardening or self-hardening. It does not work like ordinary iron and steel. Stainless iron in the heat treated condition is martensitic.

One of these products contains 18.0 to 20.0 per cent chromium, 8.0 to 10.0 per cent nickel, carbon under 0.15 per cent, phosphorus and sulphur 0.015 per cent. This material in the annealed condition has a tensile strength of 95,000 pounds per square inch, has a property of being deep-drawing. It will not corrode or rust under any condition. Tools for machining it must be kept very sharp because it has a property of becoming tough and hard. This is used for magnetic compass purposes, retainers on large generators, and can be polished to a mirror-like surface. It is being produced in all commercial forms.

H. G. LeClaire.

SCHENECTADY CHAPTER

"The program of the Schenectady Chapter of the Society for the season 1927-1928 will be devoted largely to the general problem of THE MACHINING OF METALS. It is thought that this series will be of great interest and value to all members of the Society as well as of the local technical community. The first of the series was held last Tuesday evening, October 18th, in the Rose Room of the Twentieth Century Lunch Room on Jay Street Schenectady where it is planned to hold all the meetings this year. A very enjoyable dinner preceded the meeting. J. P. Gill, metallurgist, Vanadium

Alloys Steel Co., gave us a very interesting talk on "High Speed Steel, its History, Development, Composition and Structure," which was illustrated with lantern slides. Mr. Gill gave the history of high speed steel and showed how the composition varied from the time Mushet discovered the self hardening steel up to the present time. He also explained in detail and showed very clearly in his slides the effect of time and temperature. His exhibit of tool steel of the high speed variety as well as numerous photomicrographs proved a very interesting item and the members were unanimous in agreeing that the talk was one of the best ever presented before the Chapter.

The second meeting of the series will be held on Tuesday evening, November 15, when the speaker will be A. W. Merrick, metallurgist with the General Electric Co., who will talk to us on "Recent Tests on Various Brands of High Speed Steel," as well as first hand information on experiments he is now conducting on his own brand of high speed steel." *James Taylor.*

ST. LOUIS CHAPTER

The sixty-ninth regular monthly meeting of the St. Louis Chapter of the American Society for Steel Treating was held Friday evening, October 21, 1927. While there were not any attendance records broken there were a goodly amount of members present.

After the usual dinner the meeting was called to order by W. D. Thompson, Chairman, who gave some interesting information about the Convention at Detroit, after which he introduced the speaker of the evening, M. J. R. Morris, Assistant Metallurgical Engineer, Central Alloy Steel Corp., Canton, Ohio.

Mr. Morris' subject was the use of alloy steel. This was a modern subject, as everyone present was indeed interested and enjoyed Mr. Morris' paper talk and his illustration of his points with lantern slides.

There being no further business, Mr. Morris and his associate, R. Sergeon, were given a rising vote of thanks, after which the meeting was adjourned until the next meeting which will be the 18th of November, at which time the picture, "The Age of Speed," will be shown. *C. G. Werscheid.*

TRI-CITY CHAPTER

Eighty-five members of the Tri-City Chapter of the A. S. S. T. were present at the LeClaire Hotel at the October meeting for the dinner and talk by Dr. J. A. Mathews, of the Crucible Steel Co. of New York City, entitled "The Importance of Chromium in Alloy Steel Metallurgy." The speaker referred briefly to the early developments in the use of alloys, including the work of Berthier, Faraday, Mushet, Hadfield and Riley, leading up to our present times, which may be referred to as the "Alloy Age."

After defining alloy steels, brief consideration was given to the subject of pure iron and its critical points and the effect of carbon on iron. The changes brought about broadly upon the iron-carbon critical points by the introduction of metallic elements were then considered. The specific effects of elements such as nickel, manganese and silicon were dealt with by means of

contrast to the influence of chromium, which was the principal subject under discussion. It was pointed out that chromium has a broader field of usefulness than any of the other alloying elements, since it is useful in amounts up to 60 per cent and with carbon contents over a very wide range, in some cases up to 3 per cent. Within this very broad field there are numerous patented and commercial alloys of industrial importance. Only a few of these were discussed in detail, including steels of the chromium magnet and chromium hot work types, which are of about the same composition, stainless irons and steels from 8 to 30 per cent of chromium, and finally, the high carbon, high chromium die steels, which have attracted a good deal of attention of late, containing over 2 per cent of carbon and about 12 per cent of chromium.

The hardening characteristics of these different types were dealt with, particularly as illustrating the influence of retained austenite, which subject the speaker has dealt with on several occasions, notably in the Howe Memorial Lecture for 1925. The importance of this subject of retained austenite was emphasized in explaining many of the peculiar features which arise in the heat treatment of various chromium alloys. The discussion was limited to the simple iron-carbon-chromium alloys, as this subject in itself is so vast as to preclude covering the more complicated alloys in which chromium is one of the elements.

G. A. Uhlmeier.

WORCESTER CHAPTER

The first meeting of the year was held on Friday, September 30th, in Rebboli's Restaurant, Worcester, Massachusetts. Forty members and guests were present at the supper and lecture which followed. Mr. Bigelow, chairman, made a few announcements and the reception committee was introduced to those present. Mr. Clark, our representative to the National Convention, next gave a brief outline of events that took place at the Convention. This was very interesting to all present.

The regular speaker was next introduced by Mr. Bigelow. This gentleman, Mr. H. W. Snyder of the New England Cold Drawn Steel Company, gave a talk on "Cold Drawn Steel"—a brief outline of which follows:

The method of cold working steel is quite old, dating back to the year 1400 and when we consider that about 3,000,000 tons of steel goes through this method of working each year we wonder why we do not know more about the nature of this manufacturing method.

Mr. Snyder gave an outline of the work starting with the hot-rolled bars or raw materials, then through the pickle tank which consists of an acid solution to remove scale and dirt on the surface of bar. Then, next step consists of washing in warm water followed by a lime wash. The bar is then dried and ready for the drawing. Dies used in drawing are made of hard steel, soft steel, alloy steel and cast iron. The bar is drawn through these dies and given a reduction. Lubrication is used to reduce friction. This lubrication will vary as a good many kinds are being used. The reduction that the bar receives elongates it and this has got to be allowed for in the original bar. The reduction will vary with

the nature of the work, but usually 1/16 inch is allowed. The temperature during drawing will vary from room temperature to about 400 degrees Fahr. After the drawing, the bars are straightened. This is accomplished by a roll straightener and polisher. If, after drawing, the bars are annealed and then baked, there will be no limit to the reduction, but this is too expensive to allow its practice in the cold drawn industry. Hardest dies do not give the best service. Usually a soft die is used that can readily be re-shaped or cleaned up after it gets scratched or worn. It is difficult to keep the dies to the proper shape. *C. G. Johnson.*

The Worcester Chapter of the American Society for Steel Treating enjoyed a very interesting and instructive visit to the Simonds Saw and Steel Co. on October 20. About 40 members of the chapter attended.

The Simonds Saw and Steel Co. appointed several guides to conduct groups of members through the plant, and every opportunity was afforded to observe the method of manufacturing the products of this Company. After the tour through the plant, the visiting members were conducted to the conference room of the company, and further opportunity was given the members to ask questions of the officials of the company, A. E. Remington, consulting engineer, having volunteered to answer the questions.

After this meeting, a delicious dinner was served, and at the end of the meal, Mr. Bigelow extended the thanks of the chapter, and also extended to the members of the Simonds Saw and Steel Co. an invitation to visit Worcester Chapter at any time. Following the dinner there was an interesting discussion of the point system of wage payment in use in the factory, by F. R. Jones, their general superintendent. In the course of his remarks, he brought out the fact that an increase of production resulted from the system of from 20 to 70 per cent, and that this was accompanied by a 20 per cent increase in wages, to their employees.

G. T. Sands, a department superintendent, gave the members a very interesting and instructive talk on the art of saw making, dwelling particularly on the method and reason for putting tension into the saws.

The meeting adjourned at about 7:40 p. m., and it was the general feeling of the members of the Worcester Chapter that the courtesy and hospitality of the Simonds Saw and Steel Co. could hardly be improved upon.

F. J. Connor.

November

temperature
00 degrees
is accom-
g, the bars
reduction,
n industry.
die is used
ed or worn.
Johnson.

reating en-
v and Steel

duct groups
d to observe
ter the tour
conference
bers to ask
ulting engi-

end of the
extended to
o visit Wor-
interesting
factory, by
remarks, he
a the system
20 per cent

s a very in-
particularly

neral feeling
d hospitality
oon.

J. Connor.